JUNIOR BOTANY

BY

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PREFACE.

THIS book has been written to meet the need for a good text-book for beginners, and its special object is simplicity of treatment. I have therefore tried to avoid giving overmuch detail and mentioning too many plants by way of illustration. The basis of the book is a comparatively short course of observational and experimental work which demonstrates effectively the leading principles of plant life.

It is now generally conceded that some preliminary knowledge of physics and chemistry is essential to the proper understanding of the life-processes of both plants and animals. Accordingly no apology is needed for commencing the book with an introductory course on these subjects. But for the imperative limitations of space I should have liked to extend this course considerably on the chemical side. However, teachers can easily remedy any deficiencies which they find in Section I., according to the time at their disposal.

It is not intended that the class should work through Section I. (Physics and Chemistry) before commencing Section II. (Elementary Botany). The main line of work is represented by Section II., and the teacher will easily decide on the most favourable opportunities for studying the different parts of Section I. Most of it would naturally be done in the winter months, when there is least botanical material available.

Again, the order of work in Section II. should be governed largely by the supply of material at the different seasons of the year. The main point is that there should be no attempt—for lack of some particular type of specimen on some particular date—to substitute book-reading for personal observation and experiment.

In this connection it may not be out of place to outline a rough programme for a course lasting for a year and starting in September.

September to Christmas.—Work with any plants and flowers available for Ch. VI., Ch. XI., Ch. XII. Fruits and seeds may be obtained in the field or garden or in shops for Ch. XIII., also for a start on Ch. VII. If time allows, Ch. IX. might also be worked through now.

Christmas to Easter.—Continue with work in Ch. VII. (the whole of this work on Germination can be done in the colder months); also start water cultures (Ch. VIII., Arts. 75–79). A good deal of the work in Ch. VIII. on Photosynthesis and Transpiration is possible now, the experiments succeeding quite well on warm days; this should be completed if time allows, since there will be much to be done after Easter. Much of Ch. X. can be done; also Winter buds and their opening (Ch. XI., Arts. 122–131); and any flowers available for Ch. XII. and Ch. XIV. A *Flora* (see p. 79) is useful to supplement Ch. XIV.

Easter to September.—Complete the experiments on Photosynthesis and Transpiration (Ch. VIII.). Plenty of material is now available for the remainder of Ch. X. (Arts. 103–106), Ch. XI., Ch. XII., and Ch. XIV. Using a *Flora*, work out as fully as possible the various plant communities found in the district and in those visited on holidays—moors, woodlands, the seaside, etc.

While there is no necessity for the use of the microscope in the elementary course here outlined, some knowledge of the internal structure of leaf, root, and stem is a decided advantage, and I have therefore included descriptions of the minute structure of these organs. These are illustrated by diagrams of a new type (Figs. 41, 43, 50, 51) so constructed as to minimise the danger of the misunderstandings that are so common in the case of the drawings of sections made in a single plane.

This book is based upon the syllabuses of the Oxford and Cambridge Junior Local Examinations in Botany. For this no apology is necessary, for it would be difficult to devise a better course in Elementary Botany than that outlined for candidates for these examinations.

I shall be very grateful if those using this book will let me know of any errors or ambiguities it contains, or make any criticisms which may occur to them and which may be useful in connection with a new edition whenever that becomes necessary.

F. CAVERS.

April 1915.

CONTENTS.

SECTION I.—INTRODUCTORY COURSE IN PHYSICS AND CHEMISTRY.

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INTRODUCTORY COURSE IN PHYSICS AND CHEMISTRY.

CHAPTER I.

GENERAL PROPERTIES OF SOLIDS, LIQUIDS, AND GASES.

1. General Properties of Matter.—All bodies or objects known to us consist of substances or materials of varying character, and all these substances or materials are included under the common name of *matter*. The quantity of matter in a body is called its *mass*. Different substances possess different properties, but there are certain properties which are common to all, and these are called the general properties of matter.

(1) Every body has size (length, breadth, thickness) and shape, and therefore occupies a certain portion of space to the exclusion of any other body; the measure of such portion of space is called the *volume* of the body.

(2) Every body can be divided into smaller parts—for instance, a stone or a lump of sugar can be crushed into powder, and even if we dissolve the lump of sugar in a gallon of water a portion of it exists in every drop. But we have reason to believe that there is a limit to the divisibility of matter, and that all the elementary or simplest bodies are composed of extremely small individual parts called *atoms*. The name *molecule* is given to the smallest cluster of atoms composing any substance which can exist by itself.

(3) Every body is *porous*, the pores being either visible with the unassisted eye, as in bread or cork, or requiring the aid of a microscope to make them visible or some experiment to prove that they exist. If a piece of chalk is thrown into water, air bubbles rise to the surface, the air being driven out of the pores by the water absorbed. Since all bodies are compressible, that is, can be made to diminish in volume, and since contraction or expansion results from changes of temperature, it is believed that there are vacant spaces between the molecules of all matter. This property of porosity is made use of in filtration, which consists in separating from liquids the solid particles which they hold in suspension, these particles being too large to pass through the pores of the filter.

(4) Another general property of matter is *inertia*, the negative quality of being incapable of changing its state of rest or of motion, that is, it cannot of itself either begin to move, or change either the speed or the direction of its motion if it has any; the body is, of course, understood to be lifeless.

(5) Passing over certain other properties, we come to a very important one—matter cannot be destroyed; to this we shall return later (Art. 29).

2. Solids, Liquids, Gases.—Bodies can be divided into three classes—solids, liquids, and gases. A *solid* has definite size and definite shape; the relative positions of its particles cannot be altered without the application of at least a moderate force. A *liquid* has definite size but no definite shape, it adapts itself to the shape of a vessel containing it, and its particles can be separated by the application of a very slight force. A *gas* has neither definite size nor definite shape; it tends to increase indefinitely in volume as the pressure confining it within a certain space is removed, and it always fills the containing vessel.

Gases are distinguished from liquids by their compressibility, in virtue of which they can be compressed into any volume, however small (until they liquefy), by the application of sufficiently great pressure; and by their elasticity, in virtue of which they expand when the pressure is reduced, so as always to fill the whole volume, however large, of the containing vessel and exert pressure on its sides. Gases are the most compressible bodies, solids the next, and liquids the least compressible.

It is probable that most bodies can exist in any one of the three states—solid, liquid, or gaseous; many we know do so. For instance, the liquid water when cooled becomes the solid ice; when heated to 100° C. it becomes the gas steam. On the other hand, the gases air and oxygen have been converted into liquids and solids by means of great pressure and low temperature.

3. Hints on Fitting up Apparatus.—In making experiments we frequently require to fit flasks, etc., with corks bored with one or more holes, and bend glass tubing to various angles; hence some hints on these simple operations may be given here.

(*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.

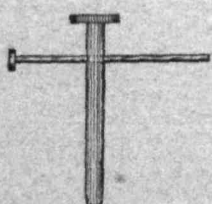


Fig. 1.

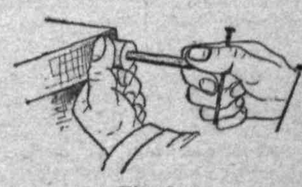


Fig. 2.

(*b*) *Bore a Cork Lengthwise and Fit a Glass Tube tightly into the Hole made.*—Select a cork-borer (Fig. 1) slightly less in diameter than that of the tube to be fitted into the cork.[1] Place the cork against the edge of your bench, as shown in Fig. 2. 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.

[1] The cork-borer is a brass tube about 5 in. 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.

Now take the cork prepared in (*a*) and bore two parallel holes in it similar in position to those in the wash-bottle (Fig. 5).

(*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 as you would a thin stick, giving a pull at the same time. Round off the sharp ends by fusing them in the Bunsen flame.

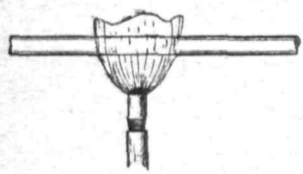


Fig. 3.

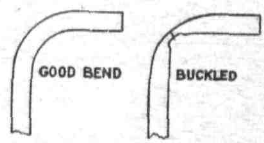


Fig. 4.

(*d*) *Bend some pieces of Glass Tubing to form Right Angles.*—Use an ordinary spreading gas flame lowered until it is about 2 in. across. Place the tube over the flame for a few seconds, and gradually bring it down into the hottest part, as shown in Fig. 3. 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, without buckling; the Bunsen flame is apt to give buckled bends (Fig. 4).

Fig. 5.

(*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. 5. Push them through the cork prepared in (*b*), and attach a nozzle by means of an inch or so of rubber tube.

4. Units of Measurement.—In the study of nature we have to deal with three fundamental ideas—space, mass, and time. In order to measure any one of the properties of a body, such as its length or mass, we fix upon a certain quantity of the same kind and call it our unit of measurement. We can then express any quantity of the same kind by specifying the name of the unit chosen, and the number of times the quantity contains that unit. The unit of time is the second, but the units of space and mass are different in different countries.

In the French or Metric system the unit of length is the *centimetre* (*cm.*), one hundredth part of the *metre*, which is the length of a platinum rod, at the temperature of freezing of water, kept in the Archives at Paris; that of volume is the *cubic centimetre* (*c.c.*), or the *litre* (equal to the cubic decimetre, or 1000 c.c.). The metre is divided into 10 decimetres (*dm.*), 100 centimetres (*cm.*), and 1000 millimetres (*mm.*). The unit of mass* is the *gramme* (*gm.*), the one-thousandth part of a kilogramme, which is the mass of a lump of platinum kept at Paris; it is very nearly equal to the mass of a cubic centimetre of pure water at a temperature of 4 degrees Centigrade (4° C.).

The Metric system has two great advantages:—(1) to convert a unit into its multiples or divisions we have only to multiply or divide by some power of 10, which we can do at sight by moving the decimal point, or adding or taking off cyphers; (2) the units of length, volume and mass bear a simple relation to one another—thus we can write down at once the volume of a body of water in cubic centimetres if we know its mass in grammes, and vice versa.

The following equivalents will be useful for reference:—

(1) *Length.*—1 centimetre = 0·3937 inch; 1 metre = 39·37 inches; 1 inch = 2·54 centimetres; 1 foot = 30·48 centimetres.

(2) *Area.*—1 square centimetre = 0·155 square inch; 1 square inch = 6·452 square centimetres.

(3) *Volume.*—1 cubic centimetre = 0·061 cubic inch; 1 litre = 0·2205 gallon; 1 cubic inch = 16·39 cubic centimetres; 1 gallon = 4·536 litres.

(4) *Mass.*—1 ounce = 28·35 grammes; 1 kilogramme = 2·205 pounds; 1 pound = 0·4536 kilogramme.

* The distinction between mass and weight may be ignored for present purposes, though in dynamics it is of fundamental importance.

(5) *Approximate Values.*—1 millimetre = $\frac{1}{25}$ inch; 1 litre = $1\frac{3}{4}$ pints; diameter of halfpenny = 1 inch; that of a penny = 3 centimetres; weight of penny = $\frac{1}{3}$ oz. = 9·45 grammes.

5. Density and Specific Gravity.—If we weigh equal-sized solid cubes of different substances, we find that the weights are different. If we take a bottle and weigh it first empty and then filled in turn with different liquids, then subtract the first result from each of the others, we obtain the weights of equal volumes of the liquids, but the weights are again found unequal. Since the weights of bodies are proportional to their masses, it follows that equal volumes of different substances may have different masses, and we define the density of any substance as the mass of unit volume of the substance; that is, density equals mass divided by volume. The number which measures the density of a substance depends not only on the substance, but also on the choice of units of length and mass. Thus the density of water = 1 gramme per cubic centimetre = 1000 ounces ($62\frac{1}{2}$ lb.) per cubic foot.

Gases, being material substances, have weight, although their density is very small compared with that of most solids and liquids; thus 1 cubic inch of water when boiled at ordinary pressure yields 1650 cubic inches of steam, but matter is indestructible, hence the mass of the steam is equal to that of the water, and its density is therefore only $\frac{1}{1650}$ of the density of water.

Specific gravity measures the same property as density, but in a different way, namely by comparing the body with a standard substance, which (except in the case of gases) is water at a temperature of 4° C. The specific gravity of a substance is the ratio of the weight of any volume of the substance to the weight of an equal volume of water at 4° C. (water at 4° C. is chosen as the standard body because it is densest at that temperature). Most gases are very light, hence it is convenient to take either air (the commonest gas) or hydrogen (the lightest gas) with which to compare them in determining their specific gravity.

When a solid is wholly or partially immersed in a liquid, it experiences an upward thrust which is equal to the weight of the liquid which it displaces. The displaced liquid is the liquid which could occupy the space below the surface of the liquid now occupied by the immersed solid; thus, when the solid is totally immersed (that is, heavier than water), the volume of the displaced liquid is equal to the volume of the solid. We can use this principle to find not only the volume but also the specific gravity of a *solid* body, whether heavier or lighter than water, or of a *liquid*.

(1) *Solid heavier than water, e.g.* a penny:—Suspend the penny by means of a piece of thread from a spring balance or one arm of an ordinary balance, and weigh (suppose the weight $W = 9{\cdot}46$ gm.); fill a beaker with water and support it so that the penny hangs (when the pan is raised) immersed to the depth of half an inch in it, brush off air bubbles adhering to the penny with a camel-hair brush or a strip of paper, and weigh again (suppose the weight $W_1 = 8{\cdot}40$ gm.).

The apparent loss of weight of the penny

$$= W - W_1 = 9{\cdot}46 - 8{\cdot}40 = 1{\cdot}06 \text{ gm.},$$

that is, the weight of water displaced by the penny is 1·06 gm.; but the volume of the water displaced is equal to the volume of the penny, therefore

the specific gravity of the penny

$$= \frac{\text{weight of penny}}{\text{weight of equal volume of water}} = \frac{W}{W - W_1} = \frac{9{\cdot}46}{1{\cdot}06} = 8{\cdot}92.$$

(2) *Solid lighter than water, e.g.* a piece of wax:—If suspended by itself the wax would float, so to make it sink we attach to it a heavy body or sinker and weigh the two together in air and in water; warm the penny used in the preceding experiment (or some other piece of metal), stick the piece of wax to it, and weigh the two in air (suppose the weight = 13·06 gm.); weigh in water as before, removing air bubbles (suppose the weight = 8·28 gm.).

The weight of the penny in air is 9·46 gm., therefore the weight of the wax in air is (13·06 − 9·46) or 3·60 gm.

The weight of the penny in water is 8·40 gm., therefore the weight of the wax in water is (8·28 − 8·40) or − 0·12 gm.

Hence the apparent loss of weight of the wax in water, which is equal to the weight of an equal volume of water, is 3·72 gm., and the specific gravity of the wax $= \frac{3{\cdot}60}{3{\cdot}72} = 0{\cdot}97$.

(3) We can find the specific gravity of a *liquid* by finding the apparent weight in it of a body which is denser than the liquid.

power. For instance, in the simplest form of hydraulic lift the cage is lifted by water pressure acting in a cylinder, the length of which is a little greater than the lift; a ram or plunger of the same length is attached to the cage, the water pressure in the cylinder forces up the ram, and when the supply valve is closed and the discharge valve opened the ram descends. The weight of the ram and cage being more than sufficient to cause the descent of the cage, part of the weight is balanced by a chain attached to the cage, passing over a pulley at the top of the lift, and carrying at its free end a balance weight.

7. Air has Weight.—It is difficult at first to realise that air is as much a material thing as the water and the earth. Gases with striking properties do not present the same difficulty. The colour of chlorine, the odour of coal gas, convince us of the reality of these. But the ever-present air, without odour, taste, or colour, appears to occupy a place by itself. If air can be weighed, it will help to convince us of its material nature.

The ancient philosophers tried to do this by weighing a bag first empty and afterwards filled with air, and as the weight did not alter they concluded that air has no weight. This shows us the danger of arriving at conclusions without testing their truth in several ways. Instead of using a collapsible bag we will take a glass flask and use a delicate pair of scales, or balance, for the weighing.

EXP. 1.—Select a flask rather large and preferably round. Fit it with a rubber cork pierced by a glass tube 3 or 4 in. long, over which is bound tightly a piece of rubber tube. Tie round the neck a piece of thin copper wire to hang the flask up by. Having seen that everything is quite dry and clean, hang the flask, together with another bit of wire, over the scale-pan of a balance, and very carefully weigh it.

Consider what we have weighed. There are flask, cork, glass and rubber tubes, two pieces of wire, and the air inside the flask.

Next suck out as much air as you can, using a glass mouthpiece so as not to wet the rubber tubing, which was weighed dry, and then double back the rubber tube, binding tightly the extra piece of wire round it to prevent air leaking back into the flask. Remove the mouthpiece and weigh the whole again.

The weight will now be found to be less than before. Since everything is present as at the first weighing, with the exception of the withdrawn air, it is reasonable to assume that the difference in weight represents that of the air sucked out.

Exp. 2.—But we can go farther than this. If you loosen the rubber tube whilst held beneath water, some of the latter passes into the flask, evidently taking the place of the removed air. Do this carefully, and measure the volume of water received by pouring it into a measuring vessel. The measurement evidently represents the volume of air sucked out, and we now know both weight and volume of this air. From your results calculate the weight of a litre of air; if your experiment has been carefully done, your answer should be somewhere near 1·3 gramme.

8. Pressure of the Atmosphere.—Since air has weight, the atmosphere must exert a pressure on all surfaces with which it is in contact. If we fill a glass tumbler to the brim with water and lay a piece of cardboard over the top, pressing it well down, the glass may be inverted without the water falling out: the card is held up by the upward thrust of the atmosphere on its under side. This upward thrust has to support the weight of the card and the thrust of the water on the upper side, besides pressing the card tightly against the rim of the glass; the pressure of the air acting upwards on the card must exceed the pressure of the water downwards, otherwise the card would fall, hence the atmospheric pressure is greater than the pressure due to a column of water of the same height as the glass.

The first actual measurement of the pressure of the atmosphere was made by Torricelli, and his experiment resulted in the invention of the mercurial barometer. A glass tube about 33 inches long and closed at one end is filled with mercury; the open end is closed with the finger, the tube inverted into a dish of mercury, and the finger removed; the mercury at once sinks and leaves a clear space at the top of the tube, while the height of the column of mercury above the surface in the cup is found to be about 30 inches or 760 millimetres. If the tube is furnished with a scale for reading off the height of the mercury, the apparatus constitutes a mercurial barometer.

The space above the mercury is practically a vacuum; strictly speaking, it contains a very small quantity of the vapour of mercury. The surface of the mercury in the dish is exposed to the pressure of the atmosphere, but that of the mercury in the tube is not exposed to any pressure; therefore the mercury must stand at a higher level inside the tube than outside, for if we could by any means lower the surface of the mercury in the tube to the same point as that outside the tube, the atmospheric pressure on the surface outside being counterbalanced by no corresponding pressure within would tend to force the mercury up the tube again.

Now, from what has already been said regarding the pressure or force per unit area in a liquid, it follows that if h is the height of the barometer in centimetres or inches, the atmospheric pressure in pounds per square inch, or in grammes weight per square centimetre, is equal to the weight of h cubic inches or cubic centimetres of mercury.

The normal height of the mercury barometer is 30 inches or 76 cm., and the density of mercury is 13·6 gm. per c.c. (*i.e.* its relative density is 13·6), hence the atmospheric pressure is $\frac{30 \times 1 \times 62{\cdot}5 \times 13{\cdot}6}{12 \times 12 \times 12} = 14\frac{3}{4}$ lb. wt. per sq. in., or $76 \times 1 \times 1 \times 13{\cdot}6 = 1034$ gm. wt. per sq. cm.

9. Barometers.—Instead of performing Torricelli's experiment with mercury, we might use a column of water, glycerine, or any other liquid to measure the pressure of the atmosphere, provided that we took a sufficiently long tube for the purpose. Since mercury is 13·6 times denser than water, the height of the water column which would exert the same pressure as a column of mercury $2\frac{1}{2}$ ft. (30 in.) high would be $(13{\cdot}6 \times 2\frac{1}{2}) = 34$ ft.; hence, unless the tube exceeded 34 ft. in height, no vacuum would be formed, and the instrument would be useless.

Apart from its great length, there are various objections to a water barometer. For instance, water evaporates freely into the vacant space, and this water vapour presses down the column; we can show this by passing a little water, by means of a curved piece of glass tubing, to the top of a mercury barometer tube: the evaporating water presses the mercury down for some distance.

The siphon barometer (Fig. 7) consists of a U-tube with branches of unequal length. The shorter branch is open to the atmosphere and corresponds to the cup of Torricelli's instrument, while the longer one is closed, and a vacuum is formed above the mercury at its upper end. The surface of mercury exposed to the air must rise and fall as much as the surface in the tube falls and rises; hence a little float is placed on it, and this is connected with a freely hanging counterpoise by means of a thread passing over a pulley. The pulley carries a pointer which moves to and fro over a graduated dial (not shown in Fig. 7).

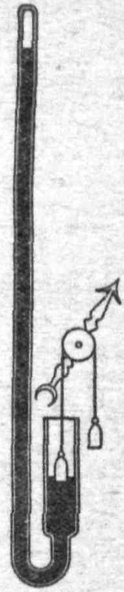


Fig. 7. SIPHON BAROMETER.

The average height of the mercurial barometer (the difference of level of the mercury in the two branches) is 30 in. or 76 cm., corresponding to 34 ft. height of a water barometer, or an atmospheric pressure of nearly 15 lb. per sq. in. (1033 gm. per sq. cm.). This pressure is called one atmosphere, but the barometer constantly rises and falls, showing that the atmospheric pressure varies within certain limits (in ordinary circumstances between about 28 and 31 in.), besides varying at different altitudes above sea-level.

Experience shows that certain changes of weather are generally accompanied by certain changes of atmospheric pressure; rainy weather is usually preceded by a decrease, while an improvement in the weather usually occurs simultaneously with an increase, of pressure.

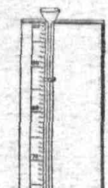


Fig. 8. BOYLE'S TUBE.

10. Boyle's Law.—As already stated, the volume of a gas depends on the pressure. Provided the temperature remains the same, the volume of a given mass of gas is inversely proportional to the pressure on the gas. To verify this law experimentally in the case of air for pressures greater than that of the atmosphere, use a bent tube (Boyle's tube) mounted on a board, with millimetre scales attached to each limb (Fig. 8).

Exp.—Pour a little mercury into the bend and adjust by shaking until the mercury surfaces are both at zero; a certain mass of air has now been imprisoned in the short limb at atmospheric pressure. Pour a little mercury into the long limb. The mercury does not rise in the closed limb as rapidly as in the open limb; this is due to the enclosed air exerting pressure. Read the two levels. Pour in more mercury and repeat the readings. Proceed until the long tube is full. Now read the barometer and note its height.

The difference in level of the two surfaces in the Boyle's tube plus the barometric height is the total pressure (P) exerted on the gas and therefore exerted by the gas. The volume (V) of the gas is found by subtracting the reading of the mercury surface in the closed limb from the reading of the top of the tube. The number obtained on multiplying P by V is practically constant.

11. Diffusion of Gases.—If we turn on a gas tap in a room for a few minutes, or take out the stopper of a bottle containing a strong scent, the smell of the gas or the scent is soon perceived in all parts of the room. This is partly due to air currents, but even if the air in the room were perfectly still, the gas or vapour would be distributed gradually through the space. That is, gases mix thoroughly and completely even against gravity—a heavy gas will diffuse upwards and mix with a lighter gas, while a light gas will diffuse downwards and mix with a heavier one.

Exp. 1.—Fill a glass jar with coal-gas over a burner and cover its open end, which must be kept downwards, with a glass plate, then set the jar over a jar of similar size and shape containing air, remove the plate, and allow the gases to diffuse for about half-an-hour, the lower jar will contain as much coal-gas as the upper one and can be lighted; yet coal-gas is much lighter than air.

The same result would be obtained if a partition of porous material, such as unglazed earthenware, were placed between the jars.

Exp. 2.—We take a piece of glass tubing 10 or 12 in. long, and close one end with a layer of plaster of Paris as follows: mix a little of the plaster with water, to form a thick cream, spread the mixture uniformly on a plate to the depth of about $\frac{1}{4}$ inch, press down in it one end of the tube, let it remain undisturbed till the plaster has nearly set (in 10 to 15 minutes), slide the end of the tube off the plate and set aside for about an hour to dry. Cover the plaster end with a cap of tinfoil, fill the tube with coal-gas, place the inverted tube with its lower end in water, about half an inch below the surface, remove the tinfoil cap, and the water will immediately rise against the action of gravity: the coal-gas passes through the pores of the plaster more rapidly than air diffuses into the tube.

EXP. 3.—We fill the tube with water, cover the plaster end with the cap, and half fill the tube with carbon dioxide (prepared by acting on limestone chips with hydrochloric acid). We remove the gas delivery-tube and the cap, and find that the level of the gas descends and displaces the water from the tube, because, carbon dioxide being a heavy gas, the air this time diffuses more rapidly through the plaster.

The rate of diffusion of gases is inversely as the square root of their densities. Hydrogen is about one-sixteenth as dense as air, hence it diffuses four times faster than air; carbon dioxide is about one and a half times denser than air, hence its rate of diffusion is about four-fifths that of air.

12. Diffusion of Liquids.—We account for the diffusion of gases by supposing that the invisible particles (molecules) of a gas are in a state of constant movement. Applying this theory to liquids, if in a solution of salt the molecules of the salt are moving in all directions through the water like those of a gas set free into the air, then if a solution of salt is brought into contact with water without shaking, the salt molecules should travel throughout the water till they become uniformly distributed in it.

EXP.—If we nearly fill a cylindrical jar with water, pour in (by means of a thistle-funnel) a strong solution of a coloured salt like copper sulphate or potassium dichromate so as to form a layer at the bottom, and leave the jar undisturbed, the two liquids will gradually mix though vibrations in the room and changes of temperature will hasten the rate of mixing, we find that diffusion takes place rather slowly.

13. Osmosis.—If we separate a solution of salt from water by a membrane like pig's bladder or parchment, diffusion will take place through the invisible spaces in the membrane, until eventually the salt particles will be evenly distributed through the water. But the rate of diffusion of the water and the solution will be unequal, the water passing through more rapidly than the salt, so that for a time the volume of the salt solution will increase, and if this solution is placed in a filled jar whose mouth is covered with the membrane considerable pressure will be set up and the membrane will bulge outwards.

Exp. 1.—Fill a jar with strong solution of salt or sugar, tie a piece of parchment tightly over the mouth, and immerse the jar in water: after a time the membrane will bulge out, and if we take the jar from the water and prick the membrane with a needle, liquid will squirt out as the stretched membrane collapses.

Exp. 2.—A better plan is to use a thistle-tube (thistle-funnel with a long tube): plug the narrow end temporarily with plasticine; pour in at the mouth enough strong (about 10 per cent.) solution of sugar to fill the head and an inch of the tube; tie over the mouth a piece of parchment or bladder; remove the plug, and fix the funnel head downwards into the cork of a jar containing water so that the sugar solution in the tube is level with the water in the jar. The liquid will rise in the tube, and some of the sugar solution will also diffuse into the water—its presence may be detected by tasting; or some of the liquid in the jar may be evaporated to dryness, when a small residue of sugar will remain.

As the liquid rises to near the top of the tube, join another piece of glass tubing to it by means of a rubber tube; the liquid may rise to a height of several feet, but eventually it begins to fall, until finally the two liquids will be at the same level, when the two solutions will be of the same strength.

Exp. 3.—If, instead of allowing the liquid in the tube to rise in this way, we use a shorter tube and join its open upper end by means of rubber tubing to one arm of a U-tube containing some mercury, we find that the mercury is pushed downwards in this arm and rises in the other arm, showing that pressure is being exerted.

The diffusion of liquids through a membrane is called **osmosis,** the passage of the water into the sugar solution in our experiment being called *endosmosis*, and that of the sugar solution into the water *exosmosis*, while the pressure exerted by the excess of endosmosis over exosmosis in the early part of the experiment is the **osmotic pressure** of the sugar solution.

CHAPTER II.

HEAT AND TEMPERATURE.

14. Heat and Temperature.—When we touch any body with the hand we can at once say whether it feels hot or cold; but it is clear that by this we simply mean that the body is hotter or colder than the hand.

If we take three bowls, one containing cold water, the second lukewarm water, and the third water as hot as the hand can bear, place the right hand in the first and the left in the third and keep them there for a few minutes, then take both hands out and plunge them together into the second bowl, the same water will feel warm to the right hand and cold to the left; after a short time, however, this feeling becomes less marked, and the water feels uniformly tepid to both hands. That is, a "hot" body is simply one that tends to impart some of its heat to other bodies near it, while a "cold" one is simply one to which other bodies tend to impart some of their heat, and when there is no tendency for heat to be thus transferred from one of two bodies to another they are said to have the same temperature.

"Hot" and "cold" are relative terms only, implying respectively more or less of the same thing. The temperature of a body indicates particular physical condition (hotness or coldness) of the body, while heat is the agency to which this condition is due. The difference between temperature and heat is of the same kind as that between the level of a liquid in a vessel and the volume of the same. Just as in Fig. 6 the level of the liquid is the same in all three vessels while the volume is different, so two bodies at the same temperature may contain very different amounts of heat. The relation between heat and temperature is such that when a body gains heat its temperature in general rises, and when it loses heat its temperature falls.

15. Mercurial Thermometer.—It is found that in general when a body is heated it expands, and will, if allowed to cool to its original temperature, gradually contract to its original volume. In general, gases expand more than liquids, and liquids more than solids, for the same rise of temperature. Other effects of heat are change of state (from solid to liquid, and from liquid to gas, with rise of temperature), change of physical properties, and chemical change.

Any physical property of a body which changes as the body is heated or cooled could be used in order to indicate the hotness or temperature of the body; but in practice we usually estimate temperatures by changes in volume. Solids are not used in thermometers—instruments for the measurement of temperature—because their alterations in size even when heated or cooled considerably are but small. Gases change volume very readily when exposed to different temperatures, and for some purposes an air thermometer is a useful instrument. Liquids are the best adapted for temperature measurement, and mercury is the best liquid for general purposes because it boils at a very high and freezes at a very low temperature, hence it remains liquid through a long range of temperature. Water has a comparatively small range of temperature between its freezing and boiling points. Alcohol is useful for measuring very low temperatures at which mercury would be frozen, but not for high temperatures because it boils at a lower temperature than the boiling point of water.

Mercury has some other advantages: it quickly assumes the temperature of any substance with which it is in contact without abstracting much heat from the substance, and it does not wet the tube.

It is preferable to use a small bulb for the thermometer because a large globe of liquid would take too long a time to change to the temperature of another substance to be tested, and would cool or heat that substance if it were in small quantity. Since the bulb is not to be large, the bore of the tube must be made very fine so that small changes in volume may be made apparent to the eye. With a large bulb we could, of course, measure the changes in volume more readily, and the degrees of the scale would be longer, or we could use a wider tube.

In making a mercurial thermometer, a bulb is blown on one end of a piece of fine tubing, the bulb is filled with mercury and heated until the mercury boils and its vapour expels the air, which bubbles through mercury contained in a small reservoir attached to the top of the tube; then the excess mercury in the reservoir is poured off, and while the whole instrument is heated a little above the highest temperature it is intended to indicate the upper end of the tube is closed by means of a blowpipe flame. If air were not driven out, it would act like a spring shut up in the top of the tube; if the top of the tube were left open, the liquid would evaporate or might be shaken out.

It now remains to mark on the tube the temperatures corresponding to different lengths of the mercury column—that is, to graduate the thermometer. To enable the readings of different thermometers to be compared with each other it is necessary to mark the points reached by the mercury when the thermometer is exposed to two constant and readily obtainable temperatures. One such temperature is the melting point of ice. Ice melts at a temperature which is very nearly the same everywhere, varying only very slightly with the pressure of the atmosphere. Hence the melting point of ice is taken as the lower fixed point, and in thermometry it plays the same part as sea level does in surveying.

We can see why there should be at least one fixed point, and if all thermometers were exactly alike no second point of reference would be required. But as tubes and bulbs all differ more or less, the same liquid enclosed in different thermometers rises to different heights for the same increase of temperature. Thus each tube requires its own scale. To make the scale of one tube comparable with that of another, all that is needed is to choose another fixed temperature, to mark again the point reached by the mercury column, and to divide the distance between the two marks into a number of equal parts. The graduation of the tube can also be continued beyond the two fixed points.

The second fixed point is obtained in connection with the boiling of water. But here it is absolutely necessary to take into account the pressure of the atmosphere at the time, for the temperature at which water boils depends on this. It also depends on the purity of the water, but the temperature of the issuing steam depends on the atmospheric pressure only. Hence the second fixed point indicates the temperature of steam issuing from boiling water under the standard atmospheric pressure, which is taken as equal to that of 760 mm. of mercury; thus an allowance must be made for any difference in the height of the barometer from the standard when the boiling point is thus marked.

The two reference marks being thus obtained, it remains to graduate the space between them. Two scales of graduation are in use. On the Centigrade scale the freezing point is taken as zero, and marked 0°; the boiling point is marked 100°. The space between *is divided into 100 equal divisions or degrees.* On the Fahrenheit scale the freezing point is marked 32° and the boiling point 212°, the space between being divided into 180 degrees; in this scale the zero is at a point 32° below the freezing point, because this was supposed by Fahrenheit to be the extreme degree of cold obtainable.

A comparison of the two methods will show that to convert a given temperature on the Fahrenheit scale into its equivalent on the Centigrade scale we must subtract 32 and then multiply the remainder by 5 and divide by 9; while to convert Centigrade into Fahrenheit we multiply by 9 and divide by 5, then add 32. Thus 68° F. = 20° C.

16. Convection and Conduction.—When any substance expands, its mass is unaltered, and therefore its density (being mass per unit volume) must diminish. So if we have any fluid unequally warmed, there will be a disturbance of equilibrium. If we warm the lower part of a mass of liquid and not the upper, the lower part will expand, becoming lighter than the liquid above, and gravity will cause them to change places, lighter liquid rising, while the colder, heavier layers sink. If the heating is continued, the colder liquid will itself become warmed until it is warmer than the rest, and so a constant motion of the particles will take place. This is called *convection*, and the particles of the liquid moving in a given direction constitute a *convection current*.

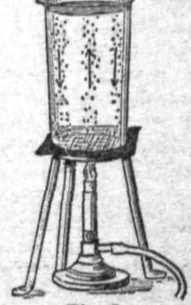


Fig. 9.
CONVECTION.

EXP. 1.—Strew some sawdust or other solid insoluble particles in a beaker of water (Fig. 9), warm it over a Bunsen burner, and note the ascent of the water up the middle of the beaker and the indraught of cold water from the top and sides.

Similar convection currents are set up in gases, as we see in the case of the draught up the chimney produced by a fire; the winds are partly of similar origin, the lower layers of the air receiving warmth from the quickly heated soil and rising upwards, while the cooler air above, and that lying over the sea, stream into its place.

Exp. 2.—We can illustrate the convection currents in air by making a hole through each end of a well-fitting lid of a cigar-box, placing a piece of lighted candle in the box exactly below one hole, and standing a glass lamp-chimney over both holes: on holding some smouldering brown paper over each chimney in turn we note the direction of the air currents by means of the smoke.

There is another way in which uniformity of temperature may be brought about, and that is by the transfer of heat from particle to particle without any bodily shifting of the particles. This is called *conduction* of heat, and in proportion as it takes place *more* or *less* rapidly through a substance, that substance is called a *good* or a *bad* conductor. Conduction is, of course, the only means by which the heat applied to one part of a solid can be transmitted to other parts of it, so as to raise the temperature of the whole. And in the case of liquids and gases, the better conductors they are the less convection will there be in them, since conduction tends to prevent the inequality of temperature, and therefore of density, on which convection depends.

Exp. 3.—The unequal conductivity of different substances may be shown by taking two long rods, say of copper and iron, fixing little lumps of wax at one end of each, and placing the other end of each in a flame. The wax on the copper will melt long before that on the iron does.

Silver and copper are two of the best conductors known, the other metals are good, while organic substances like wool, wood, and paper are bad conductors. Thus a piece of metal feels "cold" to our hands, while a piece of flannel feels "warm," not because of any difference of temperature, but because, while both are at a lower temperature than our hands, the metal being a good conductor allows some of the heat of our hands to rapidly pass away to warm all parts of the metal, while the flannel being a bad conductor lets our heat pass away so slowly that we do not notice it. We are warm when wrapped in flannel, simply because it allows us to remain warm: if we wrap a cold body, such as a lump of ice, in it, the flannel will similarly allow that to remain cold, by preventing the heat of the surrounding air from passing in. This is why flannel is used to wrap round ice and prevent it from melting.

Water is a bad conductor of heat, but is rapidly warmed uniformly throughout if convection currents are set up. If we load a piece of ice by twisting a piece of wire round it, sink it in a long test-tube nearly full of water, fix the tube in an inclined position on a retort stand, and heat it near the top, we find that the top may be boiled before much of the ice is melted.

17. Specific Heat.—If we heat equal masses of water and mercury over the same flame, we find the mercury rising in temperature much more rapidly than the water. This fact is expressed by saying that water has a much higher *specific heat* than mercury, the specific heat of a substance being the amount of *heat* required to raise the temperature of a given mass of the substance through 1° C.

EXP.—This may be best illustrated by the *mixing* of two substances of unequal temperatures. The two substances will tend to the same temperature. Suppose we took equal masses of water at 0° C. and at 100° C. respectively and mixed them—the mixture would soon come to have a temperature of 50° C., as we might expect, and it might be thought that with two different liquids the same thing would happen. But if we mixed equal masses of water at 0° C. with mercury at 100° C., we should find the temperature of the water slowly rising to about 3° C., while that of the mercury would rapidly sink to 3° C. If we took water at 100° C. and mercury at 0° C., the temperature after mixing would be 97° C.

This means that the heat given out by water in falling 3° in temperature, or the heat required to raise the temperature of water 3°, is as great as that which mercury gives out in falling through, or requires to rise through, 97° of temperature. Hence the specific heat of water is about 32 times as great as that of mercury. Similarly, the same amount of heat that will raise the temperature of 1 lb. of water from 0° to 1° C. will raise 1 lb. of sand from 0° to 5° C.

As a matter of fact, water has a higher specific heat than any other substance; hence it absorbs more heat in warming, and gives out more heat in cooling, than any other substance. Strictly, we define the specific heat of any substance as the ratio between the amount of heat required to raise the temperature of a given mass of the substance 1° C. and the amount of heat required to raise the temperature of an equal mass of water 1° C.

18. Change of State.—A good general idea of what occurs in the change of a substance from solid to liquid, from liquid to gas, and from gas to liquid again, can be obtained by using a wide-mouthed flask fitted with a cork bored by two holes, one for a thermometer and the other for a bent piece of open tubing.

Exp. 1.—Place some broken ice in the flask, cover it with water, and insert the thermometer so that the bulb is covered by the mixture. The reading of the thermometer runs down to about 0° C. and remains there. We gently heat over a Bunsen burner until the ice is all melted. The temperature does not rise so long as any ice is unmelted; that is, the heat supplied causes a change of state and not a rise in temperature.

About 79 heat-units are required to melt 1 lb. of ice into water at 0° C., that is, as much heat as would raise 79 lb. of water through 1° C.; this is called the *latent heat of ice.* Conversely, water at 0° C. gives up this amount of heat in the process of freezing.

Exp. 2.—Continue to heat the water, and note that as the temperature rises a mist forms over the surface and increases until it forces its way through the open tube; that is, the water begins to *evaporate*, or pass off into water vapour, which is invisible but becomes sufficiently condensed by the cold air in the flask to form a visible mist.

After a time, small bubbles form on the bottom and sides of the flask, rise to the surface and escape; these are simply air which was dissolved in the water and which is expelled by heat. Then larger bubbles are seen to rise rapidly to the surface from the hotter parts of the flask and break, the whole body of water being thrown into a state of commotion or *boiling*; these larger bubbles are hot vapour or steam. It should be noted that evaporation proceeds only at the surface of a liquid boiling throughout the whole volume.

The mist over the liquid now disappears, but it reappears outside the flask, showing that invisible vapour is escaping through the tube and is condensed into mist by the colder air outside. If we hold a cold object in the issuing vapour drops of water are formed on it, the vapour condensing into water. The thermometer now remains steady at about 100° C.; the heat imparted from the Bunsen is now entirely used up in turning the water into vapour; if the thermometer bulb is lifted out of the water and kept in the steam it will still read 100° C.

About 537 heat-units are required to change 1 lb. of water at 100° C. into steam at the same temperature; this is called the *latent heat of steam*.

Cooling is caused by evaporation, for whenever a liquid is converted into vapour, whether by evaporation or boiling, heat is absorbed in the process. In our experiment heat was supplied to the water, but whether heat be deliberately supplied or not, evaporation still proceeds; for instance, ponds and puddles dry up. The rate of evaporation is hastened by dryness of the air, low atmospheric pressure, high temperature (both of the water and the air), large extent of free surface of water, and renewal of air in contact with the surface (by wind).

The heat necessary to maintain this continuous process comes from the remainder of the liquid; hence a liquid by evaporation tends to cool itself and surrounding bodies.

Exp. 3.—If we pour a little ether on the hand and wave the hand about, a feeling of cold is produced, as ether evaporates very readily. If we pour a little water on a piece of wood, stand on this a beaker containing some ether, and blow with a bellows into the beaker to quicken the evaporation of the ether, the water will freeze and cement the beaker to the wood.

19. Change of Volume in Melting and Boiling.—Most substances expand in the act of melting and contract on solidification, but water is exceptional, for it contracts in melting and expands in solidifying. If we nearly fill a small flask with broken ice, add water to fill the interstices of the ice, mark the water level near the top of the neck by a thread or in some other way, and then melt the ice by gentle heat, we note that the water level falls as the melting ice contracts.

The expansion of water in freezing amounts nearly to 9 per cent., so that 11 c. in. of water at 0° C. become about 12 c. in. of ice at the same temperature; hence ice floats in water with about one-twelfth of its volume above the surface. If the water is confined it exerts great force by its expansion on freezing; if we fill a small bottle with water, cork it tightly and secure the cork with string, then put it in a freezing mixture of equal parts of ice and salt (giving a temperature of about −20° C.), in a few minutes the bottle will be burst by the expansion of the ice.

The expansion of water on freezing is of great importance in nature: the action of frost helps in forming soil from rock, and it breaks down the rough clods left by the plough into a fine seed-bed. If water contracted on freezing, the ice as it formed on the surface would sink to the bottom, exposing a fresh layer of water to the cold air; thus a spell of cold weather would convert lakes and pools into blocks of solid ice and kill the aquatic plants and animals.

If we fill a narrow-necked flask with ice-cold water from melting ice, mark the height of the water in the neck, immerse the flask in a beaker of ice-cold water, and apply heat, we find that the water contracts for a time, but on further heating, and while the water is still very little warmer than at first, the contraction stops and is replaced by expansion, which will restore the original volume, and will continue however much the water is heated. Or we may start with water from the tap and cool it by adding ice to the water in the beaker; the water will then contract until it is not far from the freezing point and then will begin to expand and continue to do so until the freezing point is reached. That is, there is a point not far above the freezing point at which a given mass of water occupies a minimum volume; this is called the temperature of maximum density of water.

This peculiar behaviour of water can be studied more precisely by the use of Hope's apparatus (Fig. 10).

EXP. 1.—Two thermometers are fitted through the side, near the top and bottom of a tall glass jar; a trough is fixed around the middle of the jar; the jar is filled with water, say at 15° C., and the trough with a freezing mixture (ice and salt). This mixture cools the water in its neighbourhood, and the behaviour of the two thermometers is carefully watched. At first the cooler layers of water sink, as we should expect, and the lower thermometer falls, the upper one remaining practically stationary; but when the lower thermometer reads 4° C. it remains stationary and the upper thermometer falls until zero is reached, when a thin coating of ice appears on the surface.

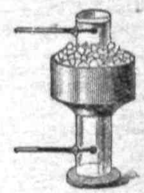


Fig. 10. HOPE'S EXPERIMENT.

This means that water has its greatest density at 4° C.; for the water cooled below 4° C. has risen to the surface, showing that its density has diminished (that is, that expansion, not contraction, is now taking place), while the lowest and densest layer remains at the bottom at a temperature of 4° C. Thus it is clear that water at 4° C. will expand whether it is heated or cooled.

We can see from this experiment what takes place during the freezing of a pond. The surface freezes, but the lowest layers of water generally remain at a temperature of 4° C. The exceptional behaviour of water is of scientific importance owing to the fact that water is the standard of density to which other substances are referred: the unit of mass in the Metric system was defined as the mass of unit volume of water at the temperature of maximum density.

Water, like all other liquids, expands in the act of boiling and contracts on condensation, the change of volume occurring being much greater than that at the lower change of state. When water changes to steam the volume is increased nearly 1700 times. The contraction on condensation may be shown by the following experiment.

EXP. 2.—Boil some water in a flask for some time, and then quickly invert into cold water in a beaker. The water rises up inside the flask, and if all the air has been previously cleared out by the boiling, the flask will be very nearly filled with water.

It might be said that the water in the flask is water produced by condensation; a very little is, but the water level in the beaker sinks as the water rises up the flask.

CHAPTER III.

NATURE AND COMPOSITION OF AIR.

20. Physical Change and Chemical Change.—We have learnt that water may, under suitable conditions of temperature and pressure, exist in at least three different states—solid (ice), liquid (water), and gas (water-vapour or steam). These are all forms of the same substance, and we say they differ physically. If by its conversion into ice or into vapour a new body had been produced differing in constitution from water, we should no longer have been dealing merely with physical change, but with chemical change. The science of Chemistry deals with the changes that matter undergoes when these involve a transference of material and the production thereby of entirely new substances. Such changes may be brought about by various agents, such as heat and electricity, but especially by the interaction of two or more substances, either with or without the assistance of heat.

21. The Combustion of Metals in Air.—We shall begin the study of chemical change by considering what changes familiar substances undergo under varying conditions in contact with the air.

Exp. 1.—Weigh carefully a small porcelain dish, and in turn place in it a quantity (about 10 gm.) of copper foil, small iron nails, sheet lead, and magnesium ribbon. In each case we weigh again, then heat the dish for about a quarter of an hour; we find that in each case there is a change in appearance (the copper and iron become covered with blackish scale, the lead is changed into a yellow ash and the magnesium into a white ash), and in each case there is an increase in weight.

It is clear that here we are dealing with something different from the conversion of ice into water, where there was no increase in weight—that is, no addition of matter.

Whatever mètal is used in this way, a "calx" (ash or scale) is produced, and as we have already found that the air has weight (Art. 7) we might guess that the increase of weight came from the air. In order to *prove* that something was taken from the air by the metals when they were heated we must confine the air.

Exp. 2.—Place a tall bell-jar in a large dish of water, mark the level of the water by a piece of gummed paper on the jar; we then ignite a piece of magesium ribbon, fixed to a cork which fits the bell-jar, place it quickly in the jar, and press the jar down firmly. After burning brightly a short time the magnesium goes out, and the water rises rapidly inside the jar, showing that the quantity of air is decreasing—hence we conclude that some of the original air has been added to the magnesium.

We then allow a short time for the jar to cool down to the atmospheric temperature, pour water into the dish until the level is the same as that in the jar (thus making the pressure of the air in the jar atmospheric, as it was at first), and mark the level of water in the jar with a second piece of gummed paper. On removing the cork and inserting into the residual air a lighted taper, we find that this air differs from ordinary air in not allowing a taper to burn in it.

We now replace the cork, take out the jar from the dish, invert it, fill it with water up to one of the pieces of gummed paper, and measure the volume (v) of this water by pouring it into a graduated cylinder. Then we similarly measure the volume (V) of the water which fills the jar up to the other piece of gummed paper.

The larger volume gives the volume of air contained in the jar at the beginning of the experiment; the difference between the two volumes ($V - v$) represents the quantity of air which has disappeared. The ratio $(V - v) : V$ is approximately $1 : 5$, that is, one-fifth of the air has disappeared.

22. Nitrogen.—The air, then, consists of two portions, one of which we may call the active constituent, the other the inactive constituent, the two being present in the proportion of about 1 : 4. The inactive constituent (Nitrogen) is easily obtained by removing the active constituent (Oxygen) from the air. This can be done in various ways, as by burning magnesium or other metals in the air.

A convenient method of preparing nitrogen is illustrated by Fig. 11.

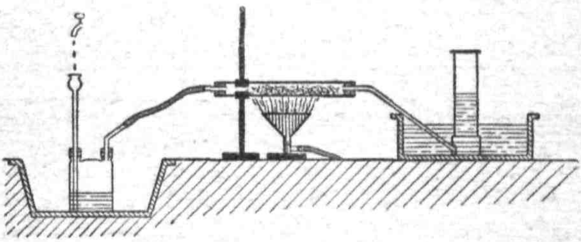


Fig. 11.—Preparation of Nitrogen from the Air.

Exp.—A piece of hard-glass ("combustion") tubing is nearly filled with copper turnings; each end is fitted with a cork; through one cork (left) passes a piece of straight glass tubing, joined by rubber tubing to a glass tube fitted into one neck of a Woulff's bottle, while the other neck of the bottle is fitted with a thistle funnel reaching the bottom (a large flask with a two-holed cork can be used instead); through the other cork (right) of the combustion tube passes a curved delivery tube, dipping into water in a pneumatic trough with a gas-jar filled with water and inverted on a stand. The combustion tube is heated until the copper is red-hot; the bottle is placed in a sink so that water drips from the tap into the thistle funnel, driving air slowly from the bottle through the heated combustion tube; as the air passes over the hot copper oxygen is retained, while the nitrogen passes on and is collected in the gas-jar, displacing the water in the jar.

If the combustion tube and its contents be weighed before and after the experiment an increase in weight will be found to have taken place; and by measuring the volume of air displaced from the bottle and the volume of the gas-jar, we could again determine the proportions of oxygen and nitrogen in the air by volume.

We find that the nitrogen is colourless, tasteless and odourless; if we watch the bubbles carefully as they rise through the water into the collecting jar, we find they do not appear to change in size as they rise, hence nitrogen is only slightly soluble in water (accurate experiment shows that 100 c.c. of water at 0° C. dissolve 2·3 c.c. of nitrogen).

If we leave a jar of nitrogen open to the air and test it from time to time with a lighted taper, we find that it is some time before the taper will burn in the jar, showing that the nitrogen has only slowly escaped, hence we infer that its density is not very different from that of air (accurate experiment shows that it is slightly lighter than air, the densities being in the ratio 14 : 14·47). If we introduce a little water into a jar of nitrogen, cover the jar, shake vigorously, and test the liquid first with red and then with blue litmus paper, neither paper changes colour—the solution of nitrogen in water is neither *acid* (turning blue litmus red) nor *alkaline* (turning red litmus blue).

Hence nitrogen is remarkable for its negative rather than its positive properties—it has no colour or taste or odour, does not support combustion, and so on.

23. Oxygen.—We must now enquire whether it is possible to recover the active constituent of air from the "calx" of a metal. If mercury is heated in the air nearly to its boiling-point a red deposit is gradually formed; this is called "red precipitate," and if we heat it to a higher temperature it changes again into mercury.

Exp.—If into a hard-glass tube we place some red precipitate and hold it in a Bunsen flame, the colour of the powder changes to black; on taking the tube from the flame and letting it cool the red colour is recovered, hence the change is not due to burning.

If we again heat the tube, in the hottest part of the flame (near the tip), a mirror is formed on the sides of the tube; if we take a splinter of wood long enough to reach the bottom of the tube, light it, blow it out, and thrust the glowing end into the tube, it bursts into flame and burns more brightly than in common air; and if we scrape off the mirror formed in the tube with the clean end of the splinter we get a liquid metallic globule of mercury.

The gas obtained by heating the "calx" of mercury, or red precipitate, is more active than ordinary air; it is the active constituent (Oxygen) of air.

24. Compounds and Mixtures.—Hence red precipitate contains two substances, mercury and oxygen, joined together in such a way that the product is an entirely different substance from either of its constituents. This kind of union is called chemical combination; both the formation of this substance by heating mercury in air and its subsequent decomposition by heat are examples of chemical change; and red precipitate is an instance of a chemical compound.

Chemical compounds are substances which can be split up into two or more new substances. Neither mercury nor oxygen has, so far, by any means been decomposed into anything simpler, hence they are examples of chemical elements. Nitrogen is also an element, as are all the pure metals, as well as sulphur, carbon, and a great many other substances; in all, about 75 elements are known, but some of them are very rare and only obtained with great difficulty. A chemical compound containing oxygen and some other element is termed an oxide; red precipitate, for instance, is oxide of mercury.

EXP.—If we mix together 1 part by weight of finely powdered iron and 1 part by weight of flowers of sulphur, heat one-half of the mixture for a few minutes over a Bunsen burner in a small porcelain crucible with the lid on, allow to cool, powder some of the product, and compare it with the rest of the mixture, we notice a difference in colour. If we draw a magnet through the two powders, we find that iron is extracted from the mixture which has not been heated, and a residue of sulphur remains—that is, the constituents have been separated by mechanical means; but no iron can be extracted from the mixture which has been heated—the iron and sulphur have combined chemically, and the constituents of the compound cannot be separated by mechanical means.

This is an important difference between a mixture and a compound.

25. Quantitative Nature of Chemical Action.—We next enquire into the *quantities* of the elements involved when a compound is formed. In carrying out a quantitative experiment which involves weighing we must exclude complications arising from causes external to the experiment. Now vessels, and especially finely divided substances, if left about, take up moisture from the air and become heavier, so we must prevent this. One way is to use an apparatus called a desiccator (Fig. 12), consisting of a glass vessel divided into two compartments communicating with each other, and provided with a lid; the upper compartment contains a pipe-clay triangle, the wires of which are bent at right angles so as to form legs, and which stands on a piece of wire gauze covering the hole between the two compartments. Crucibles, etc., can be placed on the triangle to cool; the lower compartment contains granular calcium chloride, which keeps the air in the apparatus dry by absorbing any water vapour present in the air.[1]

Fig. 12.
DESICCATOR.

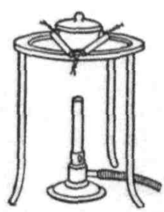


Fig. 13.—CRUCIBLE, PIPE-CLAY TRIANGLE, TRIPOD STAND, BUNSEN BURNER.

EXP.—We weigh a clean dry porcelain crucible with its lid, measure off about 12 cm. of magnesium ribbon, roll it up loosely and place in the crucible, then weigh the whole, thus obtaining the weight of the magnesium (x gm.). Then we fix the crucible on the pipe-clay triangle and the tripod shown in Fig. 13, heat the closed crucible sufficiently to

[1] Leave a fragment of calcium chloride on a watch-glass in the air of the room, and note how in the course of the day it becomes moist and increases in weight.

cause the magnesium to burn when the lid is slightly raised (without letting any white fumes escape), and when burning has nearly ceased remove the lid but continue to heat for a few minutes longer; then cool and weigh the whole, so as to obtain the weight of the white residue (oxide of magnesium) and therefore the weight (y) of oxygen which has combined with the magnesium.

If we repeat the experiment and calculate in each case the weight of oxygen combined with 1 gm. of magnesium $\left(\frac{y}{x}\text{ gm.}\right)$, we find that this works out at about 0·66. That is, magnesium oxide is always composed of magnesium and oxygen combined in the ratio 1 : 0·66 by weight.

Similar experiments with other substances lead to similar results, which are stated as the *Law of Constant Proportion*:—The same compound always contains the same elements combined in the same fixed proportion by weight.

The building up of chemical compounds from their elements is called *synthesis*, the splitting up of them into their components is called *analysis*. Matter as it exists in Nature is usually compound and complex, that is, the ordinary forms of matter are generally mixtures of chemical compounds, not pure elements or even pure compounds.

That air is simply a mixture of nitrogen and oxygen is shown by the facts that, though the composition of air varies very little under ordinary circumstances, even such small variations as are found in its composition do not occur in the case of chemical compounds; that nitrogen and oxygen retain their characters with slight modification in air, and a mixture of the two gases in the proper proportions shows precisely the same characters in all respects as air—no heat is evolved when they are brought together, nor does any contraction in volume occur; and that when air is shaken up with water a greater proportion of oxygen dissolves than nitrogen, owing to the greater solubility of oxygen, so that while in the air originally taken 1 volume of oxygen is associated with 4 volumes of nitrogen, air dissolved in water consists of 1 volume of oxygen associated with only 2 volumes of nitrogen.

26. The Combustion of Non-metals in Air.—So far we have considered the behaviour of metals towards the air when burnt in it, but there are numerous bodies which are not metals (called non-metallic) and which undergo a change when heated sufficiently in air. Among these are such substances as candle, wood, phosphorus, sulphur; candle and wood are compound substances, phosphorus and sulphur are elements.

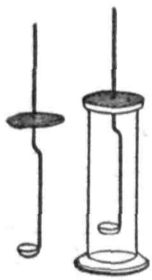


Fig. 14.—DEFLAGRATING SPOON AND GAS JAR.

EXP. 1.—If we place a small piece of candle in a deflagrating spoon (Fig. 14), light the candle, lower it into a glass jar for a short time, then remove the candle, and shake up some lime-water in the jar, we find that the lime-water turns milky.

On repeating the experiment with a splinter of wood we get the same result. Hence we infer that the jar contained a gas differing from ordinary air, in that it makes lime-water milky, and that this gas is formed when a candle or wood burns. This gas is called carbon dioxide. If we shake up some lime-water in a jar of air it remains clear for a long time, but on leaving it for some days it becomes cloudy, for the ordinary air contains a small proportion of carbon dioxide.

EXP. 2.—If we place some powdered sulphur in a deflagrating spoon and warm gently, the sulphur melts to a reddish liquid and then takes fire, burning with a pale blue flame and giving off white fumes with a strong disagreeable smell. We then plunge the spoon into a jar and press the plate down tightly. When the action ceases we pour a little water into the jar, cover the mouth with a glass plate, and shake up: the white fumes disappear. We pour a little blue litmus solution into the jar, or place a piece of blue litmus paper into the liquid: the litmus turns red, showing the presence of an acid. That is, when sulphur burns in air a gas is formed (sulphur dioxide) which has a pungent odour and which dissolves in water to form an acid (sulphurous acid).

EXP. 3.—If we cut off from some yellow phosphorus, held under water, a piece about the size of a pea, transfer it on the point of a knife to a deflagrating spoon, and dry it by touching it with a bit of filter paper, it at once gives off white fumes with a peculiar odour: the phosphorus is already reacting with the air. We then touch the phosphorus with a warm glass rod and plunge it into a jar, pressing the plate of the spoon down tightly; the phosphorus burns with a brilliant white flame, evolving dense fumes which at last settle down as a white powder; we then remove the spoon and burn off any phosphorus remaining on it. The white powder soon gives place to colourless drops of liquid, which makes blue litmus turn red. That is, the white solid (phosphorus pentoxide) formed when phosphorus burns in air dissolves in water to form an acid (phosphoric acid).

Now we enquire whether, when non-metallic substances are burned in a confined volume of air, the same portion of the air is removed as when metals burn.

EXP. 4.—We float a small porcelain dish containing red phosphorus on water in a dish, place a large bell-jar over it so that the depth of the water is about one-third the height of the jar, mark the level with gummed paper, ignite the phosphorus by touching it with a hot wire, and immediately close the jar with a cork or stopper.

The phosphorus burns brightly at first, and the heat evolved expands the gas and depresses the water inside the jar, but soon the combustion stops and the water rises above its original level; the powder (phosphorus pentoxide) formed during combustion settles down and dissolves in the water. When the water has ceased to rise within the jar, we pour more water into the dish until the level is the same in both, and mark this level with gummed paper. We test the gas in the jar with a lighted taper: it is extinguished; we find the proportion of the air which has been removed: it is about one-fifth.

This is exactly what happened in the case of magnesium, and if we repeated the experiment with other metals and non-metals we should find that all when burned in air combine with the oxygen and leave the nitrogen.

27. Preparation of Oxygen.—It is not convenient to prepare oxygen in quantity from red precipitate. There are other bodies besides oxides which give up oxygen easily on heating, either alone or with other substances. One of these is potassium chlorate. If we heat a small quantity of this substance in a test-tube, it first crackles, then melts, and at last seems to boil; on testing the issuing gas with a glowing splinter we find it to be oxygen. If we now heat some more potassium chlorate after mixing with it some manganese dioxide, we find that the mixture requires much less heating than the potassium chlorate alone.

Exp.—To prepare a quantity of oxygen, we bend a glass tube about 1 ft. long to the shape shown in Fig. 15; insert the longer end through a cork fitting a hard-glass flask; pour sufficient water into a pneumatic trough to cover its shelf by at least half an inch; fill one large jar and four smaller ones with water, invert them in the trough, and have ready some glass covers to place over the mouths of the jars when filled with gas. Fill the flask about one-quarter full with a mixture of two parts by weight of potassium chlorate and one of manganese dioxide; fix the flask in the clamp so that the delivery tube just dips below the shelf of the trough, as shown in Fig. 15; then heat with a small flame. A few bubbles of air escape at first, but soon oxygen comes over rapidly; we at once place a jar in position on the shelf, and when it is filled quickly cover its mouth while still under water with a glass plate, and replace it by a second jar, and so on.

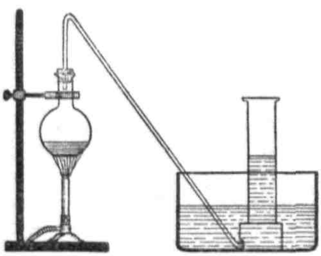


Fig. 15.

28. Experiments with Oxygen.—We now try the effect of burning in oxygen three non-metallic elements (sulphur, phosphorus, carbon) and two metallic elements (sodium, iron), using the five jars of the gas which have been obtained.

EXP.—In the first and second small jars we burn sulphur and phosphorus, as in Art. 26; the result is the same as when these substances are burnt in air, except that they burn in oxygen more vigorously. In the third small jar, to burn carbon, we wire a bit of charcoal to the deflagrating spoon, heat it over a Bunsen flame until red hot, then place it in the jar: no odour or fumes are detected; we shake up with a little water, divide into two parts, test one with litmus (acid reaction) and to the other add a few drops of lime-water (milkiness), hence the gas is carbon dioxide. Into the fourth small jar, to burn sodium, we place a small piece of sodium in the deflagrating spoon, heat strongly, and plunge into the oxygen: it burns brightly, forming white fumes of sodium oxide which dissolve in the water, and the solution turns red litmus blue (alkaline reaction).

In the large jar, to burn iron, we pour into the jar enough sand to cover the bottom half an inch deep, roll about 10 in. of thin iron wire round a glass rod to form a spiral, fasten a bit of match to one end and fix the other end to the deflagrating spoon, then light the match and plunge the wire into the jar: the wire burns, while hot globules of blue-black iron oxide fall upon the sand—this oxide is insoluble in water.

We have found that, when soluble, the oxides of non-metals (carbon, sulphur, phosphorus) produce acid solutions, while those of metals produce alkaline solutions. Oxygen is only slightly soluble in water; 100 c.c. of water at 0° C. dissolve 5 c.c. of oxygen, hence it is more than twice as soluble as nitrogen. It does not burn, but it is a supporter of combustion. All the substances which burn in air burn more vigorously in oxygen, and the products of combustion are oxides, being in some cases acid-forming oxides (from non-metals) and in others alkali-forming oxides (from some metals). In chemical properties it behaves as an exact opposite to nitrogen, which is a very inactive substance.

29. Indestructibility of Matter.—We found that both copper and magnesium when heated in air increased in weight. Although this gain in weight is not always very obvious with metals, it is still less obvious with the non-metallic substances just mentioned. It may, however, be shown that they do gain in weight; for instance, if we burn a candle suspended from one arm of a balance and absorb the gaseous products of combustion, it will be found that these products weigh more than the original candle.

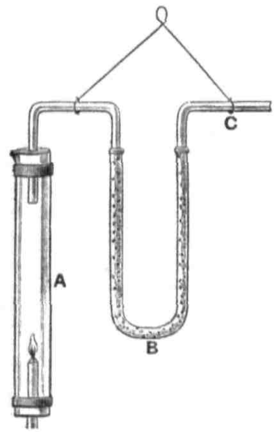


Fig. 16.—Apparatus for Experiment on Indestructibility of Matter.

We use a candle because it requires simpler apparatus than sulphur or phosphorus. This apparatus (Fig. 16) consists of a wide glass tube A fitted with corks at each end; in the lower cork are a large hole into which a thin wax candle is fitted, and smaller holes to let air in; through the upper cork a narrow glass tube passes, leading to a U-tube B which is filled with pieces of caustic soda.

Exp.—Weigh the whole apparatus. Then we connect the end of the tube C by an indiarubber tube to an aspirator (see Fig. 17) so that a current of air can be drawn through A and B, light the candle, and replace it in the tube. After letting it burn for a few minutes, we disconnect the aspirator and weigh the apparatus again—it shows a substantial increase in weight.

Thus, although the candle is disappearing, the matter is not lost; the increase in weight shows that the products of combustion absorbed by the caustic soda more than make up for the loss of weight in the candle. The substance of the candle is not destroyed, but merely assumes new forms; it is converted into water and carbon dioxide, that is, the matter of which it is composed enters into new combinations.

The candle experiment is therefore a good illustration of the indestructibility of matter. As an additional proof that when chemical changes take place matter is not destroyed, we take a clean dry flask, fit it with a good cork, cut off (under water) a small piece of phosphorus, dry it with filter paper, place it in the flask, fit in the cork, and weigh the whole; then ignite the phosphorus by dipping the flask into hot water, and when the flask is cool weigh again—the weight will be found to be the same as before, showing that no matter has been lost.

30. Carbon Dioxide in the Atmosphere.—If we shake up in a large bottle a small quantity of clear lime-water, a slight cloudiness is noticed in the liquid due to the formation of a white solid; or if we expose a dish of fresh lime-water to the air for some time, we notice a film that has formed on it. If we use baryta-water this change takes place much more rapidly, so that baryta-water forms a better test than lime-water for the presence of carbon dioxide. If we blow through a tube dipping into the lime- or baryta-water in the bottle, we find it becomes much more turbid, showing that carbon dioxide is contained in respired air.

The breathing of animals and the burning of wood and other organic (carbon-containing) substances are some of the sources of the carbon dioxide of the air (see Art. 41). The relative quantity of this gas in the atmosphere is very small, namely, 4 parts in 10,000 by volume; yet it is a very important constituent, as we shall see when we study the nutrition of plants.

31. Water Vapour in the Atmosphere.—That water vapour is present in the air even on the driest day can be proved by placing some pieces of fused calcium chloride in a dish, weighing, and exposing to the air for some time: the pieces become moist, having absorbed water vapour from the air, and if we weigh the dish we find it has gained considerably in weight. Another way is to heat some powdered blue copper sulphate until it becomes white (by losing water), and expose it to the air: it soon becomes blue again, and increases in weight, by absorbing water vapour.

It is not difficult to see where this water vapour comes from, since water is constantly evaporating from the sea and other sheets of water, as well as from moist soil; plants also give off water vapour from their leaves (transpiration).

It can be proved by experiment that a given volume of air cannot contain more than a certain fixed quantity—for instance, 1 cubic metre of air at 15° C. cannot contain more than 12·8 gm. of water vapour. When the air contains its maximum amount of vapour it is said to be saturated.

The higher the temperature of the air the more vapour is required to saturate it, so that warm air may, without being saturated, contain more vapour than is sufficient to saturate it at a lower temperature. If this air is cooled to this lower temperature, the excess of vapour will condense into water, sufficient vapour remaining to saturate the air; if the air is cooled to a still lower temperature more vapour must condense, and so on. For instance, if a vessel of cold water is brought into a warm room, water condenses on the outside of the glass; if a person wearing spectacles comes into a warm room or a hot-house, they become dimmed by the water vapour which condenses on the cold glass.

Many weather phenomena, such as dew, clouds, mist, rain, are produced by the condensation of water vapour. Take, for instance, the formation of dew. After a warm day the leaves of plants and the soil cool more rapidly than the air, the lowest layers of which then become cooled by contact with the leaves and soil. If the surface temperature falls below that at which the vapour in the air is saturated, condensation takes place and the excess water vapour is deposited as dew. The temperature at which this occurs is called the dew-point.

Exp.—In order to determine the mass of vapour present in a given volume of air we can use the apparatus of Fig. 17. We fill both U-tubes with pieces of dry calcium chloride, weigh the larger one with its contents, fill the jar (after measuring its capacity in litres) with water, securely connect tubes and jar in the position shown, and allow all the water to trickle slowly out of the jar. This will give the volume of air passing through the larger U-tube, providing all the joints are air-tight. (A jar used in this way is called an "aspirator.") The weight of water taken from the air is found from the increase in weight of the larger U-tube; the use of the smaller U-tube is to prevent any water vapour from getting back from the aspirator to the weighed tube.

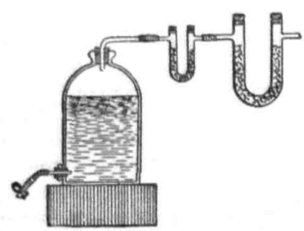


Fig. 17.—Apparatus for Determining the Percentage of Water Vapour present in Air.

32. Wet and Dry Bulb Hygrometer.—We speak of the air as being dry or moist according as we think it contains little or much moisture, but the condition of the air in relation to dryness or moistness involves (1) the quantity of vapour actually present in the air, (2) the quantity necessary to saturate the air under the same conditions. The air in a warm room may really contain more water vapour than the outside air and yet be drier, because the amount required to saturate it is much greater; for the mass of vapour required to saturate a given space increases with the temperature.

In order to determine the *relative humidity* of the air—the ratio of the mass of water vapour actually present in a given volume to the mass of vapour required to saturate the same volume at the same temperature—we need not each time perform the experiment just described. We can arrive at this ratio indirectly by using a wet and dry bulb hygrometer.

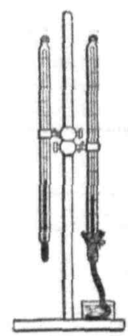


Fig. 18.—Wet and Dry Bulb Hygrometer.

This instrument (Fig. 18) consists of two similar thermometers mounted on a stand; one (dry-bulb) is used to give the temperature of the air, the other (wet-bulb) has its bulb covered with muslin which is kept moist by a wick dipping into water. The wet-bulb thermometer gives a lower reading than the other, owing to the abstraction of heat by the evaporating water. Evaporation can take place only in unsaturated air, but the saturation point (dew-point) may at certain times be more nearly approached than at others; then evaporation will be slower, and the differences between the two thermometers will be small.

Roughly, dew-point is as far below the temperature of the wet bulb as this is below the dry bulb. To find the relative humidity of the air, therefore, we multiply the difference between the readings of the two bulbs by 2, and subtract the product from the temperature of the dry bulb; this gives, roughly, the temperature of dew-point. We now refer to a table giving the weight of water vapour in grains contained in 1 cubic foot of saturated air at different (dew-point) temperatures; in some tables the weights are given in grammes per cubic metre, but this makes no difference, as it is only a *ratio* that we require.

This ratio, or relative humidity, is given on dividing the amount (W) of water vapour required to saturate the air at dew-point by the amount (w) required to saturate it at the existing temperature (that of the dry-bulb thermometer). The values of W and w are obtained from the table. For instance, if the dry-bulb reads 60° F. and the wet-bulb 54° F., the dew-point is (approximately) $60 - (6 \times 2) = 48°$ F. From the table, relative humidity $= \frac{W}{w} = \frac{3·82}{5·77} = 66·2$ per cent.

33. Table showing the Weight of Water Vapour (W) **in grains required to saturate 1 cubic foot of Air at different Temperatures** (T) **Fahrenheit.**

T	W	T	W	T	W	T	W
0	0·55	19	1·24	38	2·66	57	5·21
1	0·57	20	1·30	39	2·76	58	5·39
2	0·59	21	1·36	40	2·86	59	5·58
3	0·62	22	1·42	41	2·97	60	5·77
4	0·65	23	1·48	42	3·08	61	5·97
5	0·68	24	1·52	43	3·20	62	6·17
6	0·71	25	1·61	44	3·32	63	6·38
7	0·74	26	1·68	45	3·44	64	6·59
8	0·77	27	1·75	46	3·56	65	6·81
9	0·80	28	1·82	47	3·69	66	7·04
10	0·84	29	1·89	48	3·82	67	7·27
11	0·88	30	1·97	49	3·96	68	7·51
12	0·92	31	2·05	50	4·10	69	7·76
13	0·96	32	2·13	51	4·24	70	8·01
14	1·00	33	2·21	52	4·39	71	8·27
15	1·04	34	2·30	53	4·55	72	8·54
16	1·09	35	2·39	54	4·71	73	8·82
17	1·14	36	2·48	55	4·89	74	9·10
18	1·19	37	2·57	56	5·04	75	9·39

34. Composition of the Atmosphere.—We have seen that the air consists chiefly of two gases, nitrogen and oxygen, its average composition being nearly 77·1 per cent. nitrogen and 20·7 per cent. oxygen. The proportions of nitrogen and oxygen vary, and from various facts we know that air is not a chemical compound of nitrogen and oxygen, but a mechanical mixture. Atmospheric air results when oxygen and nitrogen are mixed in the proportions mentioned, the mixing being unattended by any manifestation of energy such as is invariably associated with chemical action; the gases can be separated by taking advantage of their different rates of diffusion; they show different solubilities in water, so that air dissolved in water and expelled from it by boiling is always richer in oxygen, which is twice as soluble as nitrogen. Besides nitrogen and oxygen, other gases are present in the atmosphere.

The average volume composition of the gases of the atmosphere may be represented, in parts per 10·000, as follows:—Oxygen, 2065·94; nitrogen, 7711·6; argon, about 79; carbon dioxide, 3·36; ozone, 0·015; water vapour, 140; nitric acid, 0·08; ammonia, 0·005. The nitric acid and ammonia, though present in small proportions, are important, for they are brought down by rain and play some part in providing nitrogen for absorption by plants from the soil water.

The presence of these two substances may be detected by drawing air, by means of an aspirator, through U-tubes containing respectively (1) a solution of diphenylamine in sulphuric acid, and (2) Nessler's reagent (a solution of mercuric iodide in potassium iodide solution): the diphenylamine solution becomes blue in the presence of nitric acid, while the slightest traces of ammonia give a yellow colour with Nessler's reagent. That these are reliable tests may be proved by adding a little dilute nitric acid to some diphenylamine solution in one test-tube, and a little dilute ammonium hydrate (ammonia dissolved in water) to some Nessler's solution in a test-tube. There are other tests for both nitric acid and ammonia, but those here mentioned are used when mere traces of these substances are to be detected.

CHAPTER IV.

NATURE AND COMPOSITION OF WATER.

35. Behaviour of Substances towards Water.—We may begin our study of the chemistry of water in a manner similar to that which we followed in the case of air, that is, by investigating the changes which familiar substances undergo in contact with water.

EXP. 1.—If we place a little cold water in a test-tube and add a few crystals of nitre or saltpetre (potassium nitrate), we find that these gradually become smaller and finally disappear from sight: the nitre has dissolved, it is soluble in water, and we now have in the test-tube a solution of nitre in water—the water is called the *solvent*, and the word *solute* is used for the substance (in this case nitre) which has dissolved.

We now add more nitre, and shake: probably this will also dissolve; but if we continue to add the solid, a point is reached at which some will remain undissolved in that quantity of water—that is, we have now a *saturated* solution of nitre in cold water. We can cause the undissolved portion to pass into solution either by adding more water or by warming the water already there; the hot water would dissolve more nitre before the point of saturation was reached, but this also would at last become saturated.

We may thus have saturated solutions at various temperatures, and clearly the quantity of solid necessary to produce such a solution depends on two things at least—(1) the quantity of water present, (2) the temperature of that water.

If we let the hot saturated solution stand for some time, the nitre will reappear, separating out in the form of crystals, but only in part—for the remaining liquid must always be a saturated solution. These crystals are usually large and well formed when obtained either by the slow cooling of hot saturated solutions or by the slow evaporation of cold saturated solutions; if the hot solution is poured into a shallow dish the crystals will be small and will separate more quickly, but in any case all the nitre will be recovered when the water has evaporated.

Many crystals when heated give off water and fall to powder. If we grind up some crystals of blue vitriol (copper sulphate) to a fine powder, weigh out 1 gm. of the powder into a weighed crucible (and lid), and heat gently over a small flame which is not allowed to touch the crucible, stirring occasionally with a platinum wire, the powder will gradually become white all through—blue particles show the expulsion of water to be incomplete, blackening shows that the heating has been too intense.

On cooling with the lid on, and weighing, we find that the amount of water driven off is about 36 per cent.; this is called water of crystallisation, and the powder is called anhydrous (without water) copper sulphate. If we drop a little water upon the powder it becomes blue again, hence dried copper sulphate serves as a delicate test for the presence of water; and if we dissolve the white powder in hot water, let the solution evaporate and set it aside to cool, blue crystals are again obtained.

Substances which do not possess a crystalline form are called amorphous: examples are chalk, charcoal, and starch.

If we fold up a circular piece of filter paper into a cone and place it in a glass funnel dipping into a beaker, then pour through it some of the nitre solution, we find that the whole of it runs through. Dissolved matter cannot be removed by filtration; in this case, to recover the solute (nitre) we must either boil off the solvent (water) or let it evaporate into the air.

Water is not the only substance capable of dissolving solids, for all liquids have this power in a greater or less degree, though any given liquid does not necessarily dissolve the same substances as another liquid. Some substances insoluble in water dissolve readily in other liquids; for instance, sulphur is very soluble in carbon bisulphide, resin in alcohol. Solids soluble in water are not soluble to the same extent, as we can show by trying a number of substances like common salt (sodium chloride), sugar, Epsom salts (magnesium sulphate), sodium bicarbonate, etc. Nitre is an example of a very soluble body, 21 gm. dissolving in 100 gm. of water at the ordinary temperature, while at 100° C. it is ten times more soluble than this.

If we shake up a quantity of chalk with distilled[1] water and let the mixture stand for a considerable time, the chalk settles down to the bottom and leaves a clear liquid above. A quantity of this clear liquid can be poured off (decanted) without allowing any chalk to be carried with it; but we could never effect complete separation by this process of decantation.

We could, however, separate the chalk and water quite easily and completely by using a filter; the liquid portion which runs through is termed the filtrate, and the chalk left on the paper the residue. If we evaporate some of the filtrate to dryness no residue is left, hence we conclude that chalk does not dissolve in pure water; but it is dissolved by natural waters, which contain dissolved carbon dioxide. The residue on the filter paper may be dried by heating at some distance over a small Bunsen flame, or in an oven, and by this means recovered in its original form.

Substances which do not dissolve in water, but which when mixed with it, even in small quantity, can still be seen, are said to be suspended or in suspension; and suspended matter can always be removed by filtration, provided the filter paper is fine enough to prevent the particles from passing through the pores of the paper. So, if we wish to separate two substances when one is soluble in some liquid and the other is not, it is only necessary to warm the mixture gently with an excess of the solvent, and filter; the insoluble portion remains on the filter, the soluble portion runs through and may be recovered by evaporation of the solvent. For instance, we can shake up nitre and chalk in some water, and recover both by using a filter.

Exp. 2.—Gunpowder contains three ingredients—nitre, which is soluble in water; sulphur, which is insoluble in water but soluble in carbon bisulphide; and charcoal, which is insoluble in either of these solvents. To separate them we shake the gunpowder with water, warm gently and filter (the filtrate contains the nitre, recoverable by evapo-

[1] *Distilled water* is water produced by boiling ordinary tap water and condensing the steam by a suitable cooling apparatus. It contains no dissolved solid matter. [Prove this by evaporating a small quantity to dryness in a dish.]

ration); we wash the residue on the filter by pouring water over it, then dry the residue, scrape it off the paper, add carbon bisulphide, shake, allow to stand, filter off the liquid from the black charcoal and let it evaporate slowly (the sulphur is thus recovered); the charcoal remains behind on the filter paper, and can be washed with a little carbon bisulphide to free it from adhering sulphur, and then dried.

When a bottle of soda-water is opened, bubbles rise in large quantities to the surface; when these bubbles have ceased coming off, the liquid can be made to effervesce again by shaking the bottle, and when shaking no longer produces effervescence a further supply of bubbles can be liberated by warming the liquid. All this effervescence is due to the escape of carbon dioxide, which was dissolved in the water and which with suitable apparatus can be collected; if we fit the bottle with a cork and a delivery tube dipping into lime-water we can prove that it is this gas. Ordinary tap water when warmed gives off a gas which can be collected; this gas consists of air and carbon dioxide which had been dissolved. The gases dissolved in water may be partially expelled on warming the water, and completely expelled on heating to the boiling point.

Unlike solids, gases dissolve better in cold water than hot. The quantity of a gas dissolved in water depends on the pressure exerted by the gas upon the water, as well as on the temperature of the water. The gas in soda-water is forced in under pressure; when the pressure is relieved by taking out the stopper, some of the gas escapes.

One litre of water at 15° C. is able to dissolve at the ordinary atmospheric pressure about 16 c.c. of air; aquatic plants and animals obtain the air they require from that dissolved in the water in which they live. As in the case of solids, some gases dissolve more readily than others. It is important to remember in various experiments that water is able to take up gases if brought into contact with them.

36. Action of Water on Metals: Production of Hydrogen.

Exp. 1.—If we take a piece of sodium about the size of a pea, drop it into a small quantity of water in a beaker, and watch what happens (looking through the side of the vessel, not over it, as a hissing globule sometimes explodes), we see that the piece becomes globular and liquid; had the sodium been placed on a floating filter paper, the temperature would have risen sufficiently to produce a flame, hence chemical action between the sodium and the water may be suspected.

We next fill a gas jar with water and invert it in a basin of water, fixing it by a clamp, then place a small piece of sodium enclosed in a piece of wire gauze and hold this below the open end of the jar: bubbles of gas are seen to rise apparently from the sodium and to collect in the jar, which when full of gas we close with a greased cover and turn mouth upwards. We bring a lighted match near, slide the cover to one side, and find that the gas burns with a yellow flame. This inflammable gas is hydrogen; the yellow colour of the flame is due to the sodium.

On rubbing the liquid in the dish between the fingers we find it is soapy; on testing it with red litmus paper we find it is alkaline; on evaporating the liquid to dryness we find the residue is not sodium (which we should expect to find if the metal had merely dissolved in the water), but is caustic soda (sodium hydroxide).

Hence we see that sodium decomposes water at ordinary temperature with liberation of an inflammable gas, hydrogen, and formation of a white solid, caustic soda, which when dissolved in water produces an alkaline solution.

If we put some bright iron nails into water, we find that after a few days the nails become rusty; iron rust is an oxide of iron combined with water.

That water alone has no action on iron in the cold or even at the boiling point is seen by the following experiment:—

Exp. 2.—Into a flask, fitted with a rubber cork through which passes a short piece of glass tubing with an inch or so of rubber tubing attached, we place some hot water and about a yard of iron wire rolled into small compass by winding it round the fingers. We then boil the water for about ten minutes, then slip over the rubber tubing a strong clip, removing the burner immediately before doing this—during the boiling the steam will have displaced the air almost completely from the flask. We turn the flask about so as to expose the wire to the space occupied by water vapour, leave it for a few days, and find that the wire remains untarnished; but on letting in air, after some hours the wire becomes rusty.

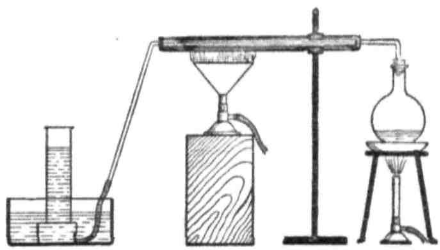


Fig. 19.—Action of Iron upon Steam.

Let us now try whether iron has any action on water (or rather steam) at a higher temperature, namely at a red heat, using the apparatus shown in Fig. 19.

Exp. 3.—Take an iron tube a foot in length and half an inch in diameter, partly filled with iron turnings or small nails; fit it at the ends with wooden corks, one pierced by a glass tube bent at right angles and passing into the flask containing some water, while through the other passes the delivery tube (completed by a piece of rubber tubing). On heating the iron tube strongly, and boiling the water in the flask (which rests on a dish of sand to prevent accidents), steam passes over the red-hot iron nails, and a gas collects in the jar. When sufficient gas has been collected, we first remove the rubber tubing, then the burner under the iron tube, and lastly, when the iron tube is no longer red-hot, the burner below the flask.

On testing the gas with a lighted match, we find it burns with a practically non-luminous flame (like that of a spirit lamp or Bunsen burner): it is hydrogen. The residue in the tube is the same blue-black substance (iron oxide) as that produced by heating iron in the air or in oxygen; that is, iron decomposes steam at a red heat with liberation of hydrogen and formation of iron oxide. *Magnesium ribbon can be used instead of iron in this experiment, the iron tube being replaced by one made of porcelain or hard glass; hydrogen is given off, and the residue left in the tube is the same substance (magnesium oxide) as that obtained by burning magnesium in the air or in oxygen.*

37. Preparation and Properties of Hydrogen.—We therefore conclude that water is a compound of hydrogen and oxygen only. If so, we should be able to obtain water by the combination of hydrogen and oxygen. Before trying to do this, we will prepare hydrogen in quantity by a more convenient method and study the properties of this gas more fully. If we introduce into a 12-oz. flask, fitted with a thistle funnel and a delivery tube (as shown in Fig. 20), 10 gm. of zinc, and add 180 c.c. of dilute sulphuric acid (made by pouring strong acid slowly with gentle agitation into 8 or 10 times its volume of cold water), we observe bubbles of gas arising from the zinc; we collect this gas in four glass jars.

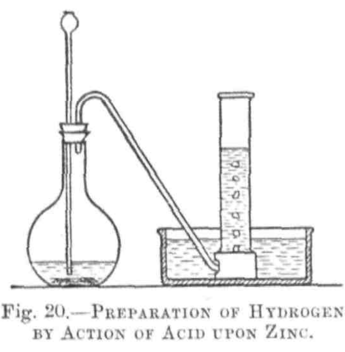


Fig. 20.—Preparation of Hydrogen by Action of Acid upon Zinc.

We hold the first jar mouth downwards and apply a lighted taper: we find that the hydrogen burns with a pale blue flame, that the burning takes place only at the mouth of the jar (that is, where it has access to air), and that if the taper is pushed up into the jar it is extinguished. We let the second jar stand on the bench mouth downwards or hold it in that position in the hand, then apply a light, and find that very little of the gas seems to have escaped. We stand the third jar on the bench mouth upwards, without cover, for a few seconds, then apply a light, and find that the hydrogen has gone. We hold a dry empty jar mouth downwards, and transfer the hydrogen in the fourth jar into it by pouring upwards: that the hydrogen escapes from the lower jar and enters the upper one is easily proved by applying a light to each jar—there will be a slight explosion in the upper jar owing to a small admixture of air during the transference, the gas burns, and moisture appears on the inside of the jar.

Hydrogen is colourless and odourless; it is not easily dissolved in water; it does not affect a litmus paper or lime-water; it is inflammable but does not support combustion; it is lighter than air (it is the lightest gas known); when it is mixed with air and a light is applied, the mixture explodes, a liquid (water) being formed.

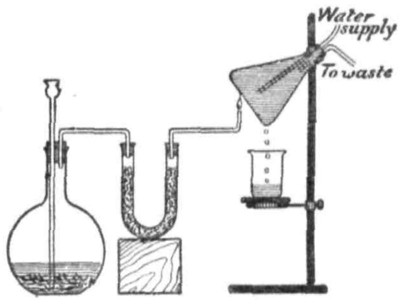


Fig. 21.—FORMATION OF WATER BY BURNING HYDROGEN IN AIR.

EXP. 1.—The last point is readily investigated by using the apparatus shown in Fig. 21, in which the delivery tube of the preceding experiment is replaced by a short one leading to a U-tube of calcium chloride (to dry the hydrogen); into the other end of the U-tube is fitted a twice bent tube, and on a retort-stand we fix a flask fitted with a longer tube attached to a water tap by rubber tubing and a shorter tube also with a length of rubber tubing dipped into a sink. By turning the tap until the flask is full of water and then letting the tap run gently we keep the flask cool. By lighting the hydrogen[1] so that the flame plays on the bottom of the flask the liquid formed by the burning of the hydrogen is condensed and drips into the beaker below.

[1] To avoid an explosion care must be taken not to light the hydrogen until all the air in the apparatus has been expelled, time being allowed for this.

That this liquid is really water is shown by noting that it is colourless, odourless, tasteless, leaves no residue on evaporation, has no action on litmus papers, its density is 1 (1 c.c. weighs 1 gm.), it freezes at 0° C. and boils at 100° C., and it restores the blue colour to anhydrous copper sulphate. Hence when hydrogen burns in ordinary air it forms water; it was called hydrogen (water-former) on this account. From our previous experiments we know that it must have combined with the oxygen of the air. We can bring this combination about in another way—by letting hydrogen act on oxides, such as those of copper or mercury (red precipitate).

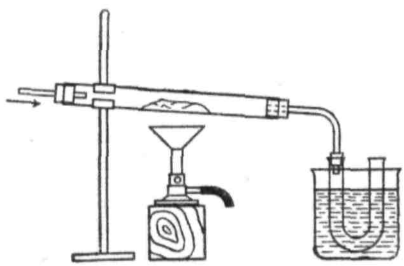


Fig. 22.—FORMATION OF WATER BY THE ACTION OF HYDROGEN ON OXIDES.

EXP. 2.—We use the apparatus of Fig. 22, placing a layer of the oxide in a piece of infusible glass tubing supported in an inclined position, connecting the higher end with a supply of dry hydrogen (as in Fig. 21) and the lower end with a U-tube partly immersed in a beaker of water; on applying heat, a liquid collects in the U-tube which can be proved to be water, while the oxide is reduced to red metallic copper or a mirror of mercury according to which is used.

By weighing the oxides before the experiment and after, and also the water formed, we could determine the proportion, by weight, in which hydrogen and oxygen combine to form water: we find that 1 gm. of hydrogen always unites with 8 gm. of oxygen to form 9 gm. of water. Water is an oxide of hydrogen.

The removal of oxygen from a chemical compound is called reduction, and substances like hydrogen which can effect this removal are called reducing agents. On the other hand, the addition of oxygen to a substance is called oxidation, and we have seen that hot copper oxide is an oxidising agent, for it gave up its oxygen to hydrogen, converting the latter into water.

38. Analysis and Synthesis of Water.—To determine the composition of water by volume we can use an electric current, as in the following two experiments.

Exp. 1.—To decompose water into its constituent elements we use a *Voltameter* (Fig. 23). This apparatus is of glass, except the wires, bearing strips of platinum foil (electrodes) fused into each limb of the U-tube; the apparatus is filled up to the bulb with water containing a little sulphuric acid, and each electrode is connected by a copper wire with a pole of a battery of four Bunsen's or Grove's cells, when gas is seen to rise from the electrodes and collect in the tubes. The gas in one tube, coming from the negative pole of the battery, proves to be hydrogen, while that in the other tube, coming from the positive pole, is oxygen; and there is roughly twice as much hydrogen as oxygen (rather more, owing to the greater solubility of oxygen in water).

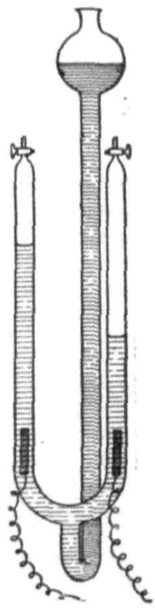


Fig. 23.
VOLTAMETER.

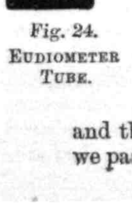


Fig. 24.
EUDIOMETER TUBE.

Exp. 2.—To find out whether this is really the proportion in which these gases combine by volume we use a *Eudiometer*. This (Fig. 24) is a long graduated glass tube having two platinum wires passed in near the closed end; it is filled with mercury and inverted in mercury. To make the explosion which occurs less violent, and the experiment therefore safer (though less striking), we pass into the tube 12 volumes of oxygen and 80 volumes of hydrogen; on passing an electric spark through the mixture there is an explosion, the mercury runs upwards, and water vapour is formed which later condenses to a little water, while 56 volumes of hydrogen remain. This means that 12 volumes of oxygen have combined with 24 volumes of hydrogen; that is, the volume ratio of hydrogen to oxygen is 2 : 1.

If we use just twice as much hydrogen as oxygen, the mercury will after the explosion fill the entire tube, showing that the gases have completely combined and that they were present in the right proportions to form water.

39. Composition of Natural Waters.—Pure water is a chemical compound of hydrogen and oxygen, and contains only these two elements. We can obtain pure water by distillation, but the nearest approach to pure water found in nature is rain-water, formed by the evaporation of water from the sea, lakes, etc. Sea water contains various dissolved salts, while some natural waters contain such enormous amounts of dissolved matter that they are saturated solutions, from which the salts crystallise out very readily; but when evaporation takes place the dissolved salts are in all cases left behind, hence the water vapour given into the atmosphere condenses into pure water. But even rain-water becomes contaminated with the atmospheric gases—oxygen, nitrogen, carbon dioxide, and traces of nitric acid and ammonia.

When rain-water runs over or through the soil it dissolves various salts, as common salt and sulphate of lime, and since the water contains carbon dioxide it is able to dissolve substances insoluble in pure water, especially carbonate of lime. Apart from dissolved solids and dissolved gases, natural waters contain more or less insoluble material in suspension; all these (dissolved solids and gases and suspended solids) are strictly speaking *impurities* in water, though they are of the greatest importance, since some of them are indispensable materials for the nutrition of plants, while the dissolved oxygen is essential for the breathing of water animals.

Ordinary spring and well waters are contaminated chiefly with calcium carbonate and sulphate, which give water its "hardness." The sensation felt when washing the hands differs with waters from different sources. With rain-water or the waters derived from sandstone areas a lather quickly forms, whilst with calcareous waters (from chalk or limestone) there is a sense of harshness and a good deal of soap is required to produce a lather—we notice also that in the latter case a scum is formed which floats on the water. Waters which readily form a lather are called soft, those that do not are called hard.

If we pass *carbon dioxide* (see Art. 41) *into some lime-water* for a considerable time, we find that the precipitate of calcium carbonate (chalk) first formed gradually redissolves; this is because calcium carbonate combines with carbon dioxide and water (carbonic acid) to form a soluble salt, calcium bicarbonate. If we make a soap solution and shake it up with (1) distilled water, (2) the solution of calcium bicarbonate just prepared, (3) a solution of magnesium sulphate, we find that a lather will appear in (1), but in (2) and (3) a scum or precipitate is formed. Thus scum is really a kind of soap which is insoluble because it contains calcium or magnesium instead of the potassium or sodium contained in ordinary soluble soap (potassium in soft soap, sodium in hard soap).

When soap is added to water containing salts of calcium or magnesium, none of it is available for cleansing purposes (*i.e.* a soap solution cannot be formed) till all the calcium and magnesium have been removed from the solution by precipitation. This explains the difference in behaviour of hard and soft waters: the former contain considerable quantities of dissolved salts, especially bicarbonates and sulphates of calcium and magnesium and chlorides of sodium and magnesium, while soft waters contain practically no dissolved salts.

If we prepare some calcium bicarbonate solution (by passing carbon dioxide into lime-water, as before), boil it till the formation of a precipitate ceases, filter, and add soap solution to the filtrate, no precipitate is formed, showing that the hardness has been removed. The explanation is that calcium bicarbonate decomposes into calcium carbonate, water, and carbon dioxide when its solution is boiled—the carbon dioxide passes off as gas and the calcium carbonate is precipitated (the "fur" in a kettle or a steam boiler is chiefly calcium carbonate produced in the process of boiling). Magnesium bicarbonate undergoes a similar decomposition when its solution is boiled, and these two bicarbonates are the chief cause of what is known as temporary hardness, *i.e.* hardness which can be removed by boiling.

Temporary hardness can also be removed by the addition of lime, which combines with the carbonic acid and converts the bicarbonates into carbonate of lime, this being then precipitated along with the carbonate originally in combination with the carbonic acid; thus if we add lime-water gradually to another portion of calcium bicarbonate solution, and when the further addition of a drop of lime-water ceases to produce milkiness pour off the clear liquid and add soap solution to it, no precipitate is formed, showing that the hardness has been removed.

The hardness due to salts other than bicarbonates cannot be removed by boiling, and is therefore called permanent hardness. When this is due to salts of magnesium and calcium it can be removed by the addition of washing soda (sodium carbonate), which precipitates the magnesium and calcium as insoluble carbonates (washing soda also removes temporary hardness, the bicarbonates being changed into carbonates). If we add a solution of washing soda to solutions of (1) calcium sulphate, (2) magnesium chloride, (3) magnesium sulphate, (4) calcium bicarbonate, till precipitation is complete, then filter and add soap solution to the filtrate, we find that in each case no precipitate is formed, showing that the hardness has been removed.

Rivers flowing through or wells sunk in populous districts may be contaminated with organic matter, discharges from works, etc. The presence of nitrogenous organic matter is a serious source of danger, since such matter forms the natural food for the development of bacteria, including those which cause infectious diseases. However, nature provides a remedy, for the nitrogenous material dissolved, say, in a river soon undergoes decomposition by the action of certain kinds of bacteria, with the formation of ammonia and other harmless products; and the ammonia is then acted on by other bacteria and by atmospheric oxygen, so that it passes finally into the form of nitric acid, which combines with metals (calcium, potassium, etc.) to form nitrates. The presence of ammonia and of nitric acid (as nitrates) can be detected by testing the water with diphenylamine and with Nessler's reagent (Art. 34).

*That ammonia and nitrates are present in soil is easily proved by placing rich (manured) garden soil in a filter, pouring in distilled or tap water, collecting the water which passes through, and testing it with these two reagents.

CHAPTER V.

CHALK, LIME, ORGANIC SUBSTANCES.

40. Chalk, Carbon Dioxide, Lime.—We shall now investigate chalk, a common naturally occurring substance which is fairly soft and is practically insoluble in pure water.

If we powder about 1 gm. of chalk, place it in a weighed crucible, note the weight of crucible plus chalk, heat strongly over a Bunsen or (better) with a blowpipe flame, allow to cool, and weigh again, we find that it weighs less than before; we heat and weigh again until there is no further change in weight, and find that the total loss is about 44 per cent. Since there has been loss in weight, the residual substance cannot be the same as the original chalk, though it resembles it in appearance.

Exp. 1.—To find out what has been lost we strongly heat some chalk in a hard-glass tube, hold in the tube a piece of glass rod that has been dipped into lime-water, and find that this becomes milky, proving the presence of carbon dioxide—the substance which chalk loses in heating.

We now add a few drops of water to the residue in the crucible—the water disappears and the crucible becomes hot, while a little steam may also be formed; next we pour a little water on some powdered chalk—nothing happens. We then touch the powder in the crucible with moist red litmus paper—the paper becomes blue, showing that an alkali is present; we repeat this with chalk—nothing happens. We now break off a small piece from a lump of fresh quicklime such as is used by builders, powder it, and repeat these experiments (adding water and testing with red litmus): the results are the same as with the residue, which is in fact quicklime (calcium oxide).

Hence chalk consists of two substances—44 per cent. of a gas, carbon dioxide, and 56 per cent. of a solid, oxide of lime.

Limestone, marble, egg-shells, and other shells are all made of the same chemical compound as chalk, namely, calcium carbonate, and all break up in a similar manner on heating, into carbon dioxide and calcium oxide.

If we place a little chalk in a test-tube and add some dilute acid (hydrochloric, nitric, sulphuric, etc.), a brisk effervescence takes place, showing that a gas is escaping, and on introducing a drop of lime-water on the end of a glass rod the lime-water becomes milky, showing that the gas is carbon dioxide. If we add some dilute acid to the residue left on burning chalk, the residue will dissolve but without effervescence, showing that all the chalk has been decomposed (if the heating has been sufficient) and that lime does not yield carbon dioxide when treated with an acid.

To ascertain whether the percentage loss in weight sustained by chalk when treated with an acid (due to the escape of carbon dioxide) is the same as when chalk is strongly heated we proceed as follows.

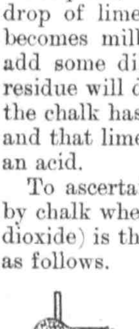


Fig. 25. FORMATION OF CARBON DIOXIDE BY ACTION OF ACID UPON CHALK.

EXP. 2.—Take a small wide-mouthed vessel (Fig. 25), fit it with a cork carrying a drying-tube filled with granular calcium chloride and with a glass tube reaching nearly to the bottom of the bottle. Accurately weigh out into the bottle about 1 gm. of chalk; pour water into the bottle till the chalk is well covered; tie a piece of thread under the rim of a small test-tube, nearly fill the tube with strong hydrochloric acid, and lower it into the bottle; next, without leaving hold of the cotton, insert the cork, so that when the cotton is held tight by the cork the tube is in the position shown in Fig. 25; then carefully weigh the whole.

Now tip the apparatus so that a *little* acid escapes from the tube on to the chalk, repeating this till all the chalk has disappeared: carbon dioxide is evolved and first drives air out of the flask through the calcium chloride tube (its only exit), the gas itself then passing out, while any moisture carried by the escaping gases is retained by the calcium chloride, preventing loss in weight due to this cause. Next, to expel the carbon dioxide filling the bottle and dissolved in the liquid, we warm the bottle gently (not boiling it), and then attach a piece of rubber tubing to the calcium chloride tube and suck gently until the pungent taste of carbon dioxide is no longer noticed, and the flask is now full of air again; after it has become cold, we weigh again, and find that the loss in weight is about 44 per cent.

41. Preparation and Properties of Carbon Dioxide.—The action of acid on chalk or limestone affords a ready method of preparing carbon dioxide in quantity and examining its properties more fully.

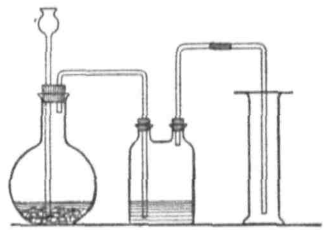


Fig. 26.—Apparatus for Preparation of Carbon Dioxide.

We place some lumps of chalk or limestone in a flask fitted with a thistle funnel reaching nearly to the bottom and a delivery tube of the shape shown in Fig. 26—the long arm of this tube passes nearly to the bottom of a Woulff's bottle containing a little water (to dissolve any hydrochloric acid, a very soluble gas, that may accompany the carbon dioxide). We then pour into the thistle funnel enough water to cover the chalk, and then some strong hydrochloric acid, and collect three or four jars of the carbon dioxide (keeping the mouth of the jar covered with cardboard while filling), and let the rest bubble through a small quantity of distilled water in a fourth jar. To find out when each jar is full hold a lighted match near its mouth, when the heavy overflowing gas will extinguish the flame.

Exp. 1.—To show the heavy nature of carbon dioxide pour a jar of the gas into another and larger jar in the bottom of which a bit of candle is burning: the flame is extinguished. Another proof of its high density is obtained by sprinkling some powdered chalk or whiting in the bottom of an inverted bell-jar, pouring on it some dilute hydrochloric acid, then blowing a soap-bubble into the jar: the bubble will float where the carbon dioxide and air meet.

EXP. 2.—To show that carbon dioxide really contains carbon we ignite a piece of magnesium ribbon tied to a deflagrating spoon and plunge it into a jar of the gas: the metal continues to burn and we find along with the white magnesium oxide black specks of carbon. These could not have come from the magnesium, for it is an element; hence they have come from the compound gas, which has also supplied oxygen to the magnesium.

EXP. 3.—We then divide the water through which the gas bubbled into three parts. To the first we add a little lime-water: the milkiness produced proves the presence of carbon dioxide. We heat the second to boiling and note the escape of gas bubbles, then add lime-water: no precipitate is formed, the boiling has expelled the dissolved carbon dioxide.

We taste the third, then add to it a little neutral litmus solution (prepared by adding dilute hydrochloric acid drop by drop to some blue litmus solution until the colour changes to *purple*): the reddening shows the presence of acid, though the liquid is not distinctly sour.

The gas itself was formerly called "carbonic acid," but the dry gas does not make a dry neutral litmus paper red, so the term is incorrect. On heating the red liquid till it boils we find that as the gas bubbles escape the colour gradually changes to purple, showing that the acid is disappearing.

The apparatus (Fig. 26) should be used for the experiments in Art. 39, the gas being passed into lime-water.

Besides the carbon dioxide expelled when limestone rocks are heated, much is given off by decaying vegetable matter in the soil, and water passing through soil permeated with this gas takes it up in solution, so that all natural waters contain more or less carbon dioxide. This gas is constantly being added to the atmosphere in various ways—as by the respiration of plants and animals, decay of organic matter, burning of carbon and substances containing it (coal, wood, etc.), and subterranean causes.

These and other sources contribute so much carbon dioxide to the atmosphere that this would gradually get more and more charged with this gas, and the percentage of oxygen would diminish, but for processes constantly in operation which act in the opposite direction. Thus, in the process of carbon assimilation in plants, the green colouring matter (chlorophyll) in diffused or direct sunlight effects the decomposition of carbon dioxide and liberates oxygen; while carbon dioxide, being fairly soluble in water (at 15° C. water dissolves about its own volume of carbon dioxide at ordinary atmospheric pressure), is carried down by rain, and is also taken up by lakes, rivers, and the sea, providing submerged water plants with their supply of carbon.

42. Action of Heat on some Organic Substances.—If we place in a series of test-tubes some powdered sugar, some powdered starch, some paper (a piece of filter paper or other white paper folded up into small compass), and some wood (a few match-sticks broken into small pieces), and heat each gently in a Bunsen flame, we find that the results are very similar. These experiments should be made and the exact changes noted. In each case the substance darkens and gives off water (a colourless liquid condenses in the cool part of the tube and this turns anhydrous copper sulphate blue) on heating gently; on heating more strongly dirty white fumes are evolved which have a pungent smell, are inflammable (apply a match to mouth of tube), and have an acid reaction (hold a wet piece of blue litmus paper in the tube); and the final residue is a black mass (charcoal).

All these substances are compounds of carbon, hydrogen, and oxygen (in paper and wood other elements are also present to a smaller extent), and all these compounds are closely related to each other. In each case the hydrogen and oxygen are present in the proportion required to form water. When any of these substances is heated much of the hydrogen and oxygen is driven off in combination as water; the remainder of the hydrogen and oxygen comes away, in combination with a small percentage of carbon, as various compounds, one at least of which is an acid and one at least is inflammable; while the residue consists of carbon, associated in the case of paper and wood with a small quantity of mineral matter.

If we place a small piece of lighted coal on a deflagrating spoon, lower it into a jar of oxygen, and after the coal has stopped burning test the contents of the jar for water by anhydrous copper sulphate and for carbon dioxide by lime-water, we find that the products of combustion are carbon dioxide and water (steam).

Vegetable matter consists of a mixture of complex compounds composed chiefly of the elements carbon, hydrogen, oxygen, and in smaller proportion nitrogen, sulphur, phosphorus, and certain metals. Coal has been produced by the gradual decay and consolidation of vegetable matter, during which the greater part of the hydrogen and oxygen is driven off, so that coal consists chiefly of carbon but contains a small percentage of the other elements mentioned. We have seen that when coal burns the carbon is chiefly converted into carbon dioxide and the hydrogen into water. Now let us see what happens when we distil coal out of contact with air, as is done in gas-works.

Exp. 1.—For the dry distillation of coal, or of other organic substances, we may use the apparatus shown in Fig. 27, in which A is a hard-glass tube containing dry coal dust, while the test-tube B is almost completely immersed in a beaker of water. On heating the tube A we notice the formation of brown fumes, which mostly condense in B, where a liquid collects which separates into two layers. On placing in the fumes issuing at C a paper moistened with lead acetate solution we find the paper becomes blackened : this is due to the formation of *sulphuretted hydrogen* and shows the presence of *sulphur* compounds. If we hold a drop of lime-water on the end of a glass rod in the fumes it becomes milky, proving that *carbon dioxide* is present.

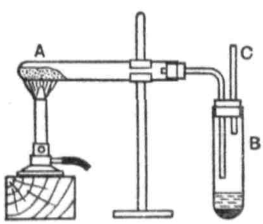


Fig. 27.—Apparatus for Dry Distillation of Organic Substances.

After a time we apply a light to the gas at C, and find it burns with a luminous flame: it is coal gas. When the flame goes out we disconnect the apparatus, and test the light-coloured upper layer of liquid in B with red litmus paper: it turns blue, showing the presence of alkali. We place a little of this liquid in a watch-glass, add some caustic potash solution, and even if we cannot detect the characteristic smell of *ammonia*, we find that this gas is given off, for a moistened red litmus paper held above the liquid soon turns blue: the formation of ammonia proves the presence of *nitrogen*. The thick dark-brown lower layer is *coal tar*. We then break the tube A and note the hard *coke*. If we heat this strongly in a crucible, it burns, leaving a residue of ash.

That the blackening of the lead acetate paper is due to the formation of sulphuretted hydrogen (hydrogen sulphide) is easily proved by preparing a little of this gas by heating iron sulphide with dilute hydrochloric acid in a test-tube and, besides noting the characteristic rotten-egg smell of the gas, testing it with lead acetate paper. That the blueing of red litmus paper is due to the presence of ammonia is shown by heating a mixture of sal-ammoniac (ammonium chloride) and quicklime in a tube: fumes of ammonia are given off and if we dip a glass rod into hydrochloric acid and hold it in the mouth of the tube a white deposit of ammonium chloride is formed on the rod (by the combination of the ammonia with the acid).

Ammonia is also produced when organic nitrogen-containing substances are heated with alkalis like potash or soda-lime, and may either be smelt or proved to be present by the blueing of red litmus paper held over the mixture and by the formation of ammonium chloride on a rod bearing a drop of hydrochloric acid.

Exp. 2.—Instead of coal, we may make a dry distillation of crushed-up seeds, pieces of roots or stems, leaves, etc.; instead of a glass tube for A we may use a piece of iron tubing corked at each end, and instead of the test-tube B a flask set in a beaker of cold water; and we could make the distillation *quantitative*. To do this we take the tissue (roots of Creeping Buttercup answer well) and weigh it, then place it in an oven at about 100° C. (or in a dry tube held in a beaker of water which is kept boiling) for about an hour or until no further loss in weight is found; this gives us the amount of free water present in the fresh tissue, and the *dry weight* of the latter. We then place the dry tissue in the tube A and heat it until it becomes charcoal; the difference between the weight of the charcoal and that of the dried tissue gives the weight of the products of distillation (water and tar, ammonia, sulphuretted hydrogen, and other gases) of the organic substances in the tissues. We then transfer the charcoal to a weighed crucible, heat strongly, and find the weight of the ash left.

The ash contains various compounds (salts), the elements present not being necessarily combined in the same ways as in the original tissue (since the action of heat results in the formation of new combinations of these elements), and we could make a qualitative analysis of it exactly as is done in the case of a mixture of salts—that is, we could test the ash for calcium, magnesium, iron, potassium, sulphuric acid, phosphoric acid, etc., by applying to different portions of it (dissolved in water or in acids) the reagents which, by the formation of precipitates, reveal the presence of these substances.

SECTION II.

ELEMENTARY BOTANY.

CHAPTER VI.

THE PARTS OF A PLANT.

43. Seed Plants (Flowering Plants).—In this book we are not going to deal with all the various divisions of the Vegetable Kingdom, but only with the highest group, that made up of the Flowering Plants, or Seed Plants, so called because if we follow out their life-story we find that sooner or later the plant produces a *flower* or a number of flowers, and a part of the flower becomes changed into the *fruit*, which contains one or several *seeds*. The ripe seed contains a young plant, or *embryo*, and after a longer or shorter period of rest, usually during the winter, the seed (which has either fallen from the plant, or, more often, been carried away by wind or by birds) *germinates*. That is, its embryo begins to grow again, bursting the coverings in which it is wrapped, and becomes in time a full-grown plant.

Even the largest tree begins life as an *egg*, but this egg is so small that it can only be seen with the help of a microscope; so in tracing the life-story of a plant we shall start from a later stage than the egg. The young plant (embryo) contained in the seed has grown from the egg and has after a time stopped growing, becoming dormant though remaining alive. Just as a hen's egg contains a store of food which serves to nourish the chick until it breaks the shell and comes out able to get food for itself, so in a seed we find a store of food at the expense of which the embryo plant feeds until it breaks out of the seed-coat and gets its root into the soil and its shoot into the air and then begins to find food for itself. Some seeds are very small, others larger than the eggs of some birds, but in all cases there is enough stored food to give the young plant a start in life. We ourselves live largely upon the stores of food which plants and animals provide for their young, and the kinds of food stored are much the same in both plants and animals. Our own food, like the food of all animals and all young plants, consists of a mixture of substances, the chief of which are carbohydrates, oils, and proteins: we shall study these later. In addition, all living beings require water and certain mineral salts, but water is not strictly speaking a food in the case of animals, while salts are made use of by plants in a very different way from that in which animals use them: this also we shall study later.

As already stated, the life-story of a flowering plant begins and ends with the seed. The plant itself may last only for a few months, or for many centuries, before it dies. In any case, like all living things, it must, in order to remain alive and to grow, do many things which are summed up by saying that unless it is adapted to, or in harmony with, its *surroundings* or *environment*, it will fail in the struggle for existence and for increase, for this struggle is as real and stern among plants as among animals or mankind. A plant is, like any other living thing, a machine, and an efficient machine, or it could not keep alive and growing, and the various parts of which it is made up perform different kinds of work, or different functions. To do their work efficiently, the different parts are more or less widely different in their structure, both outer and inner, and this is expressed by saying that the plant shows division of physiological work, the word physiology being used in the same sense in plant life as in animal life and meaning the study of the functions performed by the various parts of the plant.

In order to get clear, even though at first limited, notions about plant life it is not enough to study only the structure, or only the functions, of plants. We must keep both things always in mind, for one helps to explain the other. One or two other points may be mentioned here. If we study any locality, or *habitat*, in which several different kinds of plants grow together —for instance, a marsh, a wood, or a hedgerow—we find that some of the plants are better fitted than the others in some particular way. For instance, in a marsh some plants are tall, others growing among these are much shorter, others again grow on the wet soil or float on the water; in a wood we have the tall trees, below these other shorter kinds of trees or shrubs, below these again a number of still shorter herbs, and so on; in a hedgerow we have the Hawthorns or other trees making up the hedge itself, growing up among them climbing plants like the Bryonies or Honeysuckle, and growing below them a variety of herbs.

In many such cases all the different plants seem to be growing quite well, forming a society or community so peaceful in appearance that it is only on reflection that we realise the struggle for existence that is really going on between them. Each kind of plant in such a community, growing in the same habitat, is an efficient machine, though some of the plants possess certain advantages over the others. For instance the Bryonies, Vetches, and other climbers in a hedgerow reach the light and air at the top very quickly and easily by supporting their weak stems on the firm stems of other plants, instead of slowly building up firm stems of their own. Again, Daisies and Dandelions are both widely scattered over a lawn or field, though the Daisies have, as compared with the Dandelions, heavy seeds without the beautiful parachute-like mechanism which enables the Dandelion seed to be so easily carried about by the wind.

To sum up this argument, we find that there may be many efficient types of plants growing in the same habitat and differing, often in a striking way, from each other as to single advantages, and yet equally successful when we consider the sum total of their equipment for the struggle for existence. This seems a very obvious conclusion, yet it is apt to be forgotten; that is, when we see a plant which has a striking biological advantage such as plumed or winged seeds, we are apt to wonder why other plants do not possess the same efficient mechanism.

Another point to bear in mind is that plants, in order to be successful in the struggle for life, must either be able to live in various habitats or else take refuge in special habitats where the struggle may be less intense because fewer plants grow there. For instance, we know that all flowering plants which grow in water have been driven from the land by stress of competition with other land plants. Again, plants are efficient for life within more or less wide ranges of change in their surroundings. The most obvious of such changing conditions of life are the changing seasons. In our climate the cold of winter stops the active growth of plants, and the race or species would die out unless some part of the plant were able to perennate, or endure from year to year during the winter season, besides storing food for later active growth.

The best method of perennation is that by seed, for the seed is able to resist extremes of temperature in a higher degree than other parts of the plant; plants which die down after producing their seeds, leaving only these to survive the winter and to store up food for at least the beginning of next year's growth, are called *annual* plants, while some plants may complete their life cycle from seed to seed more than once in a single year and are called *ephemeral* plants (*e.g.* Shepherd's Purse, which may be found germinating, flowering, and forming seeds at almost any time of year). When other parts than the seeds, either above or below ground, are able to resist the winter and to last from one year to the next, carrying forward life and food, the plant is called *biennial* if it lasts for two years, *perennial* if for more than two years.

Biennials (*e.g.* Canterbury Bell, Turnip) produce leaves during their first year (the year in which the seeds germinate) and flowers in the second year. In perennials the persistent parts are either above ground, and in that case usually hard and *woody* (shrubs and trees), or protected by being underground (rhizomes, tubers, bulbs, corms), in which case the plant is (like annuals and biennials) *herbaceous* (with soft tissues).

To put it briefly, plants are adapted, or fitted by some change or *adaptation* in their structure, to contend with the varying conditions to which they are exposed. The plant is a living and sensitive thing, an object or centre upon which many forces of the outer world act, and its life is made up of continual responses, or reactions, to these forces which together make up its environment. If the plant's adaptations and responses to these forces are suitable, the plant remains alive and efficient; if not, it suffers or perishes altogether.

44. Root and Shoot.—All flowering plants, with a very few exceptions, show a distinction into *root* and *shoot*. The shoot may be divided into a *reproductive* part and a *vegetative* part, consisting in each case of *stem* and *leaves*. Hence the different organs of the plant fall into two divisions—reproductive organs (inflorescence, flower, fruit, seed) which are concerned with the life of the *race*, and vegetative organs (root, stem, foliage-leaf) which are concerned with the life of the *individual*. A sharp line cannot always be drawn between these divisions, for the vegetative parts often serve to propagate the plant, and in some cases roots give rise to shoots: the reverse (shoots giving off roots) is very common.

We may begin by examining some common annual herbaceous plants with the shoot erect, a plant of this kind being free from the complications often seen in those which last more than one year, or those which are adapted for creeping below or above ground, climbing, etc.

Four very common and easily recognised annuals, which may be found in flower at practically any time of year, are Shepherd's Purse, Chickweed, Groundsel, and Red Dead-nettle. These and any other plants available, whether or not described in this book (see Index), should be examined and compared. The vegetative organs may be studied also in the seedlings dealt with under the heading of Germination (Chapter VII.).

45. Broad Bean Seedling.—In a well grown seedling,[1] about a foot in total length, or an older plant if available, note the **root** which has grown downwards from the seed, and the **shoot** which has grown upwards from the seed.

(*a*) In the **root** note the main vertical *root axis*, or primary root, tapering gradually to the free end or root-tip; and the *rootlets* arising from the main root, the oldest (farthest from root-tip) being longest. If these first branches of the root have in turn given off branches, note that while the former all grow in the same slanting downward direction from the main root, the latter grow out at right angles to *their* parent-root, so that some may grow upwards instead of horizontally or downwards.

Scrape different parts of the main root with a finger-nail or the back of a knife, and note that, while the younger parts consist of soft tissue, the older parts have a hard central core (the *vascular cylinder*). That this contains woody tissue is easily shown by cutting the root across and also longitudinally and applying to the cut surface a solution of aniline sulphate or chloride (made by dissolving the salt in a little alcohol, then adding water to make up a 10 per cent. solution, and then a little dilute sulphuric or hydrochloric acid according to whether the sulphate or chloride has been used)—the central tissue is stained yellow. That this solution is a test for *wood* is shown

[1] For directions as to sowing of seeds, etc., see Art. 51.

by dipping into it a wooden match: if the match does not soon turn bright yellow, add more acid to the solution.

Note that each rootlet appears first as a small projection on the surface of the root, and that the older ones appear to have broken out and made a slit in the surface; cut the root across, and also longitudinally, at places where rootlets come off, and

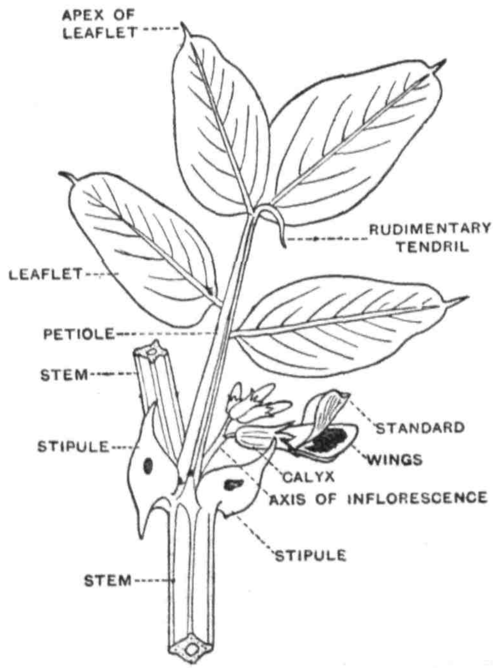


Fig. 28.—PART OF A BROAD BEAN PLANT.

note that each rootlet starts from the central tissue and pushes its way out to the surface.

Note that the rootlets are arranged in definite longitudinal rows on the main root, usually five rows in Broad Bean; on cutting a thin slice across the main root at a point where a young rootlet comes off, and placing it in a drop of aniline sulphate solution on a glass slide, you can see that the central cylinder contains five strings of wood, and the rootlet comes out exactly opposite one of these strings—this explains the arrangement of the rootlets in five longitudinal rows, for every rootlet starts just outside a wood strand.

(*b*) Root hairs are better seen in other seedlings, especially on the roots of Cress, Wheat, etc., grown in muslin-covered jars of water or in moist air. If an old enough Bean seedling is not available, the points in root structure above mentioned can be seen on digging up and examining the root of Shepherd's Purse, Groundsel, or other annual plant; the root hairs are better seen if the root is rinsed in water and the plant supported on a piece of cardboard with a hole in the centre and a slit cut from this to the edge of the card, so that the root can hang into a jar of water.

(*c*) In the **shoot** (Fig. 28) note (1) the *axis* or *stem*, four-sided and hollow except at the base; the *foliage-leaves*, in two rows corresponding to two opposite ridges of the stem; (3) the *buds*, which in a well grown plant may have grown out as lateral branches, each bud or branch arising in the *axil* of the leaf—*i.e.* in the angle between leaf and stem and just above the insertion of leaf on stem. In one seedling cut the stem across at several places, in a second cut it longitudinally, also scrape the surface with a finger-nail or blunt knife: the outer tissue is soft and greenish, and in the youngest part of the shoot all the tissue is soft, but in the older parts white strings are seen arranged in a series a little below the surface, and that these contain wood is shown on testing cut surfaces or sections with aniline sulphate solution. The arrangement of the branches depends on that of the leaves, not on the position of the woody strands as in the case of the root branches; the stem branches, like the root branches, simply repeat the structure of the parent axis.

(*d*) In the uppermost part of the shoot the young leaves are closely crowded over the growing shoot-tip and are folded up, but as growth proceeds they become spaced out on the stem and spread out from it. Carefully pick off some leaves, and note that (except in the two lowest leaves) each *leaf* consists of (1) a stalk, or *petiole*, grooved above; (2) the *stipules*, a pair of outgrowths at the base of the petiole, each roughly like half of a spear-head in form; (3) the *leaflets*, thin flat oval structures with a pointed tip; (4) a prolongation of the petiole above the leaflets—this outgrowth, sometimes developed as a small flat leaflet, is evidently a *rudimentary tendril*, as may be inferred by comparison with the tendril-bearing Vetches and Peas related to the Broad Bean.

(*e*) Examine a leaflet closely, noting the thick chief "vein" (*midrib*) running up the middle, the smaller veins coming from this, and the still finer veins which form a network; scrape and cut the petiole, which has woody strands like those of the stem: that the veins of the leaflet also contain woody tissue can be shown by steeping a leaflet in alcohol until the green colour is removed and then treating it with aniline sulphate solution. The upper surface of the leaflet is darker green than the lower surface. Tear the leaflet across in such a way as to pull off its thin colourless skin-layer and expose the green inner tissue. Try both surfaces, and note that while the lower skin can be torn off with hardly any green specks attached to it, it is more difficult to tear off the upper skin. The leaflet therefore consists of a thin colourless skin (*epidermis*) above and below, and a thick middle green tissue (*mesophyll*) which is denser towards the upper surface and looser towards the lower, and which contains the veins.

(*f*) Trace the root upwards and the shoot downwards to their junction with the two large *cotyledons* which lie within the ruptured seed-coat. The lower foliage-leaves are simpler in form (*i.e.* have only two leaflets) than the upper ones. The two lowest (first-formed) leaves above the cotyledons are rudimentary and scale-like, usually only slightly green, and consist of three lobes joined at the base, but they agree with the other leaves in having a bud in the axil. A bud is also present in the axil of each cotyledon; hence the cotyledons are *leaves* ("seed-leaves"), though in this plant differing markedly in appearance from ordinary (foliage) leaves. In some cases one or both of these buds may have grown out to form branches.

Examine also younger seedlings, working back to the earliest stages in germination (Art. 52).

46. Broad Bean Flower and Fruit (Figs. 29-31).—In order to trace the formation of the seed, we should examine the *flower* which has produced it. If flowers of this plant are not available at this stage, they may be examined later in fully grown plants raised in a garden border or in pots or boxes of soil; or we may examine the very similar flowers and fruits (pods) of French Bean, Scarlet Runner, Sweet Pea, Garden Pea, Gorse, or some other member of the Bean family (Papilionaceae). The flowers of the Broad Bean are arranged in small clusters, each cluster (*inflorescence*) arising in the axil of a leaf and being therefore a kind of branch. Only a few flowers are produced by each flower-bearing branch, but we notice that the individual flowers are stalked and spaced out on the axis; this kind of inflorescence is called a *raceme*, the youngest flowers being nearest the top. Note the parts of a single flower, starting from the outside:—

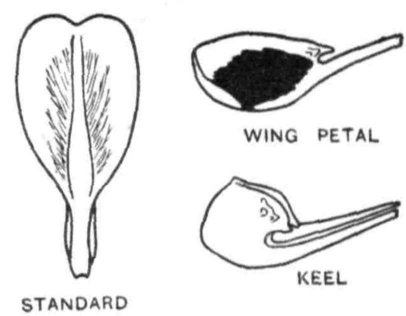


Fig. 29.—Corolla of Broad Bean Plant.

(1) The *calyx*, a colourless or greenish cup, with five pointed lobes at its free edge; veins run up from the bottom of the cup, one going up the middle of each lobe, others between the lobes.

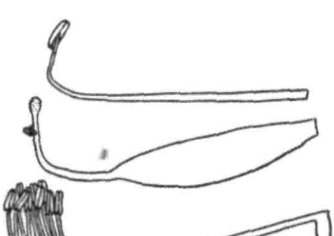


Fig. 30.—Stamens and Pistil of Broad Bean.

(2) The *corolla*, consisting apparently of four pieces, a large upper piece (*standard*), two smaller side-pieces (*wings*), and a lower boat-shaped piece (*keel*); the standard overlaps (*i.e.* its edges fold over the upper edges of) the wings, which in turn overlap the keel. The standard is on the upper (posterior) side of the flower, *i.e.* the side towards the axis of the inflorescence, and the other parts are symmetrically arranged on each side; the calyx-lobes alternate with the parts of the corolla, the odd lobe being the lowest one.

Open the calyx by cutting or tearing it between the two upper lobes, remove it, and spread it out. Then remove in turn the standard, wings, and keel from the *receptacle*, *i.e.* the expanded end of the flower-stalk to which all the parts of the flower are attached: note that each wing is locked with the keel by means of a series of folds, and that the keel is carried on two distinct stalks and can be very readily separated into two pieces which come apart along the sharp lower edge of the keel. The corolla consists in reality of five pieces (*petals*), and these alternate in position with the calyx lobes; the calyx consists of five parts (*sepals*), which are united below but free above.

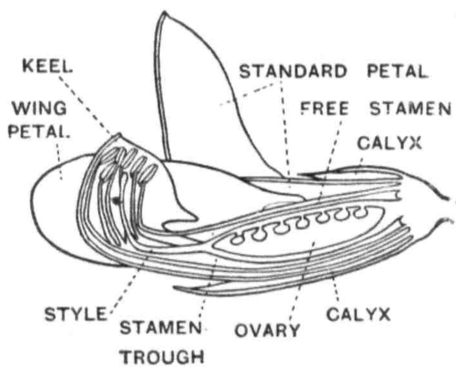


Fig. 31.—Longitudinal Section of Broad Bean Flower.

(3) The *stamens*, seen on opening up the keel, are ten in number, each consisting of a small oblong body (*anther*) carried at the end of a thin stalk (*filament*); the uppermost stamen is free (*i.e.* its stalk can be traced down to the flower receptacle), but the remaining nine are united below to form a kind of trough. Examine an anther with a lens, noting the two lobes divided by a longitudinal groove and each showing a less marked groove (the large anthers of Lily, Iris, etc., show this more clearly); the anther consists of four *pollen-sacs* lying side by side, but this can only be seen in a young flower, for in an older one the anther will have opened by two slits to allow the yellow dust-like *pollen* to escape.

(4) The *pistil*, seen on removing the stamens, consists of a lower hollow portion (*ovary*) containing a number of "young seeds" (*ovules*) attached along the upper side of the cavity, and a slender outgrowth (*style*) arising from the free end of the ovary and bearing a tuft of hairs just below its slightly swollen tip (*stigma*).

In a *pod* of Broad Bean note that the corolla and stamens have withered, the former having fallen off though the remains of the stamens may be seen, while the calyx persists around the base of the pod, which has clearly developed from the ovary. The pod readily splits open along its upper and lower sides into two parts (*valves*), the splitting taking place from above downwards, and the *seeds* (the ripened ovules) are arranged in two rows, so that one row occurs along the upper edge of each valve; each seed is attached to the edge of the valve by a broad flat *stalk*. Compare pods in different stages of development, and note the changes in texture and colour undergone by the shell (*pericarp*) of the pod and by the seeds themselves during ripening. If Broad Bean pods are not available, examine the pods of the other plants mentioned.

47. How to use this Book.—A course in Plant Study, or Botany, is in some respects very different from one in Physics or Chemistry, where all the materials for practical work can be obtained at any time and all this work is done indoors. It is hardly possible to take the various parts of Botany in a strictly logical order when, as is the case here, we want the reading of the book to go along with practical work, without which mere reading about plants is useless. This book is meant only as a guide as to which plants should be studied carefully as types, either because they are easily obtained, or have the various parts on a large enough scale to be easily made out, or are suitable in other ways for illustrating the many modifications which the parts of plants undergo to fit them for special uses or functions.

There is only one way in which one can get any real knowledge of plant life, namely, by taking every opportunity of carefully observing the plants themselves and by making experiments with them. There are two kinds of practical work to be done: (1) Plants or parts of plants should be carefully examined, dissected and sketched to scale as accurately as possible; (2) experiments should be made, and their objects, methods, results and inferences noted, sketches being also made of the plants or plant-parts and the apparatus used.

48. Materials for Study.—Since the life-story of a Flowering Plant begins and ends with the seed, the seed would appear to form a good starting-point for our study of plant life, and as the seeds of some plants, like Beans or Peas, are of a large size and have easily visible parts, we should begin with these. Besides, we shall need growing plants of handy size for various experiments, and seedlings, or young plants arising from the germinating seeds, are very convenient for experimenting with.

It would also be an advantage to choose for our first studies some plants which run through their whole life-history within a year or less, so that we could either watch the same plant from start to finish, or have different plants of the same kind showing all stages between germination and fruiting. It is not always possible to have all these stages to examine on the same day, or even in the course of a few weeks; but by observing an annual plant from time to time, or by sowing its seeds indoors or in a garden, we need not have long to wait before we can piece together the stages in its history from seed round to seed again.

Annual plants have the further advantage for purposes of study that they are free from the complications of structure required by plants lasting more than one year (biennials and perennials), which must store up food and protect their buds during winter, these necessities involving various modifications in the parts above or below the ground.

But at whatever time of year we begin we need not look far to find plenty of material for study, nor do we need to know the names of a great number of plants at the start. A few bags of seeds would afford enough material to keep us busy for months with plant physiology, and most of the experiments given in this book can be done at any time of the year. There are some 1300 different species of Flowering Plants growing wild in Britain, and at least as many again are cultivated in gardens or green-houses, but there is no need to know more than a few dozens by name in order to acquire a very fair stock of knowledge about the life of plants, provided they are carefully studied. We should, of course, get to know a fair number of the commoner plants growing in this country, particularly those which either show special adaptations or which grow in special habitats.

In order to identify the plants, that is, to find out their names if we do not already know them, we can either ask other people or else look them out in a book. This book only gives the names of a few plants, perhaps quite enough for our purpose, but it is useful to have a book specially intended to enable us to identify any plant we find growing wild in Britain. A book of this kind is called a "British Flora," and there are several such books. Bentham and Hooker's *British Flora* (Lovell Reeve & Co.) is in two volumes, one with descriptions and the other with pictures (9s. each volume); a smaller book, less complete but quite sufficient for our purpose, is Watts' *School Flora* (Longmans, Green & Co., 3s. 6d.). At any rate, there should be no difficulty in recognising and obtaining for examination the plants named in this *Junior Botany* book as examples of various structures and adaptations.

During winter use should be made of materials available (vegetables, flowers, fruits, bulbs, corms, tubers, etc.) in greengrocers' shops, gardens, and nurseries, as well as those found growing wild; seeds should be sown and their germination studied, experiments being also made with the seedlings; the twigs and winter buds of trees and shrubs should be dissected and studied. In spring the opening of buds should be studied, as well as the flowers now available. In summer the work on opening buds and on flowers should be continued, besides that on plant physiology; this is the best time for getting to know plants when in flower and for studying the vegetation of ponds, streams, marshes, moors, sandy shores, salt-marshes, etc.

In late summer and autumn observations should be made on the ripening of fruits, methods of seed dispersal, and the preparations made for the winter resting period by plants which last more than one year—in the case of perennial herbs the dying down of the above-ground parts and the persistence of underground organs (bulbs, tubers, rhizomes) which store food and bear bulbs which later grow up into new shoots at the expense of this stored food, in the case of trees and shrubs (apart from evergreens) the falling of the leaves and the other changes for the winter rest. These hints are very general, but serve to show that there is plenty to be done in studying plant life all the year round, so that we need never be idle for lack of work to do and need not even in winter fall back upon merely reading about plants instead of studying them for ourselves and by observation and experiment finding out all we can about them.

49. Drawings.—It is practically useless to write descriptions of observations on plant structure, or of experiments on plant physiology, or of the plants found growing in special habitats, unless you add careful drawings of the plants or parts observed or the apparatus used in experiments. The drawings should be done in pencil, not in ink; it is not worth while spending time in shading, clear outlines will do. They should be done to scale as nearly as possible, and in most cases on a large scale, each drawing being marked with " × 1 " if of the natural size, " × 2," " × 3," etc., if enlarged to twice, thrice, or more times the natural size.

Either a drawing-book should be used, or a book made up of alternate leaves of ruled writing-paper and good plain drawing-paper, the notes being written opposite the drawings; the parts of the drawing should be marked by either writing the name of each part at the end of a line drawn from it, or by writing at the end of each line a letter (*a*, *b*, *c*, etc.) or a number (1, 2, 3, etc.) and writing out on the opposite page, or below the drawing, the name and description of each part thus marked. Also write, below or opposite each drawing, the name of the plant, the part of the plant, the aspect represented, any dissection that has been done to the specimen, etc. In the case of experiments, drawings should be made of the plant or part experimented with, of the apparatus used, of the appearance of the plant or part before and after the experiment, and so on.

CHAPTER VII.

GERMINATION.

50. Broad Bean Seed.—Examine (1) dry seeds, (2) seeds that have been soaked in water for two days.

(*a*) Note the shape of the ripe seed. At the thicker end there is a black or brown mark (*hilum*)—obviously the *scar* formed when the seed became detached from the stalk which fixed it to the inside of the pod.

(*b*) Examine from time to time dry seeds that have been placed in water: the dry seeds are light and hard, but become softer and heavier (Art. 55) after lying in water for a day or two. At first the surface is thrown into folds—evidently the coat at first absorbs water and swells more rapidly than the seed-contents, hence it becomes loosened and is easier to remove in a well soaked seed.

(*c*) Drop some dry seeds into very hot (just boiled) water, and note the air-bubbles that escape from near the hilum: the heat of the water makes the air inside the seed-coat expand, and it is forced out of an opening in the coat.[1] Wipe dry the hilum end of a soaked seed, and squeeze the seed—water oozes out of a small slit-like pore (*micropyle*) at one end of the scar.

(*d*) Remove the coat from a soaked seed, starting at the end opposite the scar. Note the two large whitish *cotyledons,* whose slightly concave inner sides are pressed against each other. After stripping off the upper half of the coat, pull off the rest of it (the part covering the scar end) entire like a cup. Note the

[1] This is a good method for showing the presence of air in, and of pores on the surface of, leaves or stems as well as seeds, but in all cases we must see that there are no damaged places where air would escape instead of (or as well as) from natural openings.

smooth tapering *radicle*, projecting from between the cotyledons and pointing towards the micropyle end of the hilum; also note the little *pocket* on the inner side of the seed-coat, into which the radicle fits.

(*e*) Pull apart the cotyledons, and remove one by breaking across the short stalk by which it is joined to the thickest part of the radicle. Note the curved *plumule*, lying between the cotyledons, fitting into a groove on the inner surface of each cotyledon, and forming a continuous curved line with the radicle. Examine the plumule carefully with a lens, and with a pin turn back the minute *foliage-leaves* which it bears.

(*f*) Make *sketches*, at least twice the natural size, of (1) the entire soaked Broad Bean seed, from the scar end; (2) same from the front—*i.e.* thicker edge—showing the micropyle and the bulge caused by the radicle; (3) same in side view; (4) side and (5) front views of embryo after removing seed-coat; (6) scar end portion of empty seed-coat, showing the pocket into which the radicle fits; (7) side and (8) front views of embryo with one cotyledon broken off; (9) section of whole seed, cut between the cotyledons, to show pocket with radicle fitting into it. Some points (structure of plumule, micropyle, wrinkling of coat during absorption of water) are more easily made out in the seeds of French Bean and Scarlet Runner (Art. 53).

51. Materials and Apparatus for Study of Germination.—Get dry ripe seeds of Broad Bean, French Bean, Scarlet Runner, Pea, Sunflower, Marrow, Oak (acorn), Mustard, Cress, Radish, Castor Oil, Maize, Wheat, Onion, Date (the stone); also the fruits (pods) of Beans and Pea, and a fruiting Sunflower head. In each case place some of the seeds in water to soak for a day or two, and get together the following simple pieces of apparatus:—

(1) Ordinary flower-pots or boxes filled with moist soil, or sawdust, or coco-nut fibre, or moss (Sphagnum); the boxes should have some holes bored in the bottom, for drainage, and at least one box should be about a foot deep for the long roots of Bean seedlings.

(2) A lidless wooden box with one of its sides removed and replaced by a sheet of glass sloping downwards and backwards, so that the roots in growing down will press against the glass

and thus be more easily observed; the glass side may be simply held in position by a row of tacks or nails at either side, so as to be movable when desired.

(3) A few shallow unglazed pots ("seed-pans"), each with a glass sheet to cover it.

(4) A few cylindrical lamp-glasses, filled with moist sawdust, and supported in a pot of sawdust; soil, fibre, or moss may be substituted for sawdust.

(5) A few glass jars or tumblers filled with water and covered with coarse muslin tied over the mouth; these are to be used for the smaller seeds.

(6) A few large glass jars containing a little water, and each fitted with a cork to the lower side of which soaked seeds can be fixed by means of pins; if large corks for these "moist-air jars" are not available a piece of soft wood, to cover the jar and pin the seeds to, will do quite well—in either case a hole should be bored to let air in.

(7) Take a large wide-mouthed glass jar, dry inside, and cut a rectangular piece of dry blotting-paper with one side equal to the height of the jar and the other a few inches longer than the circumference of the jar; roll the paper, insert it in the jar, fill up the jar with dry sawdust (or fibre or moss), place seeds in different positions between paper and glass, and pour in enough water to wet the sawdust and the paper thoroughly.

Sawdust is liable to become foul, owing to the growth of bacteria, causing the roots to rot; coco-fibre and moss (Sphagnum) are cleaner, but should be taken out now and then, if used for a considerable time, sterilised by being boiled in water, and replaced in the pots and boxes. Most of the apparatus above mentioned will be useful later on in various experiments where we wish to keep plants under observation from day to day.

The smaller seeds (*e.g.* Wheat, Onion, Cress, Mustard, etc.) should be placed on the muslin-covered jars, after filling these with water so as to keep the seeds moist. When the other seeds mentioned have been soaked in water for a day or two, place them in the boxes, pots, and jars above described, so that the stages in germination may be easily observed. Some of the pots and boxes should be placed out of doors, others kept indoors; most of these seeds will germinate in a fairly warm room in winter, but some of them (especially the Date and the Marrow) will require to be set in a heated greenhouse or a hot-bed, or near a boiler or hot-pipes, or any other warm place available.

Four boxes or pots should be sown with samples of all the seeds, one being placed out of doors, the second in a room at ordinary temperature, the third in a warm but light place, and the fourth in darkness; the differences in rate of growth and in the appearance of the seedlings in the four cases should be carefully noted.

When these various arrangements have been made, or while they are being made, we may be examining the larger seeds, beginning with the beans and peas; but it is perhaps better to begin with the seedlings and work back to the seeds.

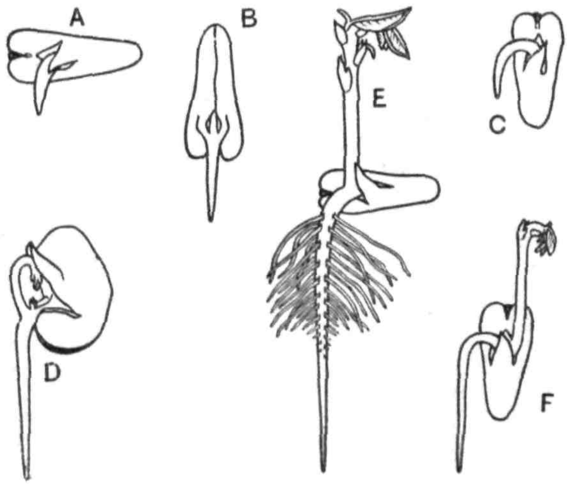


Fig. 32.—STAGES IN GERMINATION OF BROAD BEAN SEEDS, PLANTED IN VARIOUS POSITIONS.

52. Stages in Germination of Broad Bean Seed (Fig. 32).—These stages, as seen in a series of seedlings or in the same seedling examined from time to time, may be summarised as follows:—

(1) A V-shaped split is formed in the seed-coat along the edge of the radicle pocket, caused by the radicle swelling and

pushing off the outer wall of its pocket as a triangular flap, the apex of the triangle not reaching the micropyle.

(2) The radicle emerges from the burst coat in advance of the plumule, and it grows downwards no matter what position the seed may have been planted in, curving when necessary in order to take this vertical downward course.

(3) The split extends from the two ends of the V until it reaches some distance along each side of the seed, exposing the cotyledons to view.

(4) The stalk of each cotyledon lengthens sufficiently to push the cotyledons apart and make room for the plumule to emerge from between them.

(5) The plumule grows vertically upwards, in whatever position the seed has been planted, its lower part curving if necessary in order to take this direction.

(6) The plumule for some time after emerging is hooked, its tip being bent downwards on the side facing the seed itself, owing to the opposite side of the stem growing at first more rapidly, but gradually straightens out as it grows upwards.

(7) The first foliage-leaf is on the side of the stem farthest from the seed, the second one is opposite to it and higher up.

(8) The cotyledons remain in their original position within the torn coat, and gradually become wrinkled and shrivelled as germination proceeds.

(9) The bud in the axil of each cotyledon may have grown out to form a branch, especially if the plumule has grown badly or been damaged.

(10) Roots may grow out from the base of the plumule, especially if the radicle has grown badly or been injured.

The seedling has evidently grown from the whole of the seed-contents, *i.e.* everything inside the seed-coat, for we have seen that 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 (sometimes called the *caulicle*) of which the lower portion (*hypocotyl*) merges gradually into the radicle, the middle portion bears the cotyledons, while the upper portion (*epicotyl*) bears the young foliage-leaves and together with them forms the plumule.

53. French Bean, Scarlet Runner, Pea.—Examine seeds and seedlings of these plants on comparison with Broad Bean. In the seeds of the first two note the position of the hilum on the concave side of the kidney-shaped seed; the conspicuous micropyle, with a raised margin; the wrinkling of the seed-coat during soaking; and the two large primary foliage-leaves of the plumule, each folded along the midrib, one leaf folded over the other, and each showing veins running from midrib to margin of leaf. In the Runner the cotyledons are *hypogeal*, remaining below ground, while in French Bean they are *epigeal*, being carried above ground by the elongation of the hypocotyl.

Most seedlings have epigeal cotyledons, and in these two beans it is easy to show—by making a series of Indian ink marks across the axis of the very young seedling, starting at the insertion of the cotyledons, and noting the position of these marks as growth proceeds—that while the radicle end of the caulicle (the apparent young root, or part of the axis below the cotyledons) grows downwards, the part just below the cotyledons grows rapidly upwards, carrying up the cotyledons and the plumule.

The first two foliage-leaves of these two seedlings are broad and heart-shaped in outline, and stand opposite each other at the upper end of the first "joint" of the plumule (this lower part of the plumule can be seen in the seed itself as a stalk lying between the insertion of the cotyledons and that of the two first foliage-leaves), while the upper part of the plumule (which remains for some time as a small bud while the two primary foliage-leaves are growing larger) bears leaves which are compound, having three leaflets, and are arranged singly on the stem.

Note that in the French Bean seedling the part emerging from the soil is hooked; as we have seen, this part is the *hypocotyl*, and in other seedlings with epigeal cotyledons we observe the same thing, whereas in hypogeal seedlings like Broad Bean and Pea it is the plumule which is hooked.

In the Garden Pea the transparency of the coat enables us to see clearly in the soaked seed the hilum, micropyle, and radicle, all lying in the same straight line, with the tip of the radicle pointing to the micropyle; the cotyledons are hypogeal, and the earlier foliage-leaves resemble those of Broad Bean, but the upper leaflets of the later leaves are developed as tendrils.

In French Bean and Runner the rootlets are arranged in four longitudinal rows on the main root; in Garden Pea they are usually in three rows.

54. What Conditions are necessary for Germination?—The Broad Bean seeds whose germination we have studied were first steeped in *water*, then placed in moist *soil* (or sawdust), the water used being ordinary tap water (which contains dissolved air and a certain amount of dissolved *salts*); they were exposed to *light* during the daytime; they were supplied with a certain amount of *heat*; and they have grown in the *air*. We have now to enquire whether all these six things are absolutely necessary to make the seed germinate; we are not at present concerned with its later growth into a strong healthy plant. In order to find out we must take these things one by one, and compare two seedlings, or two sets of seedlings, of the same plant in each case, one set being supplied with all these things, while the other is deprived of the thing into whose necessity for germination we are enquiring.

For instance, to find out whether soil is essential for germination we compare a Broad Bean seedling grown in soil with another grown in sawdust, the two being placed close together and given the same conditions in all other respects (water, heat, light). The seedling grown in soil will be seen after some time to be stronger and healthier than that grown in sawdust; but in both cases the seed germinates, hence soil is not essential for germination, and we can make use of this fact by letting seeds germinate on muslin tied over jars of water in order to examine them more conveniently than if they were sown in soil. To find out whether the salts in tap water are essential we can place two sets of small seeds of the same kind (*e.g.* Wheat) on two muslin-covered jars containing respectively tap water and distilled water: in both cases germination takes place. We shall now deal with the other conditions (water, light, warmth, air) under which our seeds have germinated.

55. Water needed for Germination.—If we place some dry Broad Bean seeds in dry sawdust, others on the surface of moist sawdust in a box, and others an inch below the sawdust in the same box, we find that the first seeds do not germinate at all, the second ones slowly absorb water from the wet sawdust, while the third ones soon germinate but not so rapidly as seeds which have first been soaked in water. To find out whether liquid water is essential, we pin a seed to the lower side of the cork of a jar containing a little water: the seed gradually absorbs water from the moist air, as proved by weighing it from time to time, and may obtain enough water in this way to enable it to germinate slowly.

Are the "dry" seeds, as taken from a quite ripe pod or bought from a seedsman, quite dry? If we warm some seeds gently in a test-tube we notice drops of water which have condensed in the upper part of the tube. To determine the amount of water which "air-dry" seeds contain we chop up some seeds into pieces or crush them in a mortar, weigh, and then dry thoroughly without any scorching or charring, by placing the material in an oven or a water or sand bath for an hour or more. The result shows that the apparently dry seeds really contain a certain amount (perhaps 10 per cent.) of water—not sufficient to allow of germination taking place, but sufficient (and necessary) for the seeds to remain alive and capable of germinating.

By repeating this experiment twice or thrice for any given kind of seed, *e.g.* Broad Bean, we obtain the dry weight of the seed—say, 90 per cent. of the weight of the "air-dry" seed—and can use this for experiments where we wish to compare the dry weight of seeds and seedlings.

That the water present in the resting seed is essential is shown by the fact that a seed kept in an oven, even at a comparatively low temperature, until no further loss in weight takes place—*i.e.* until all the water has been driven off—does not germinate: it has been killed, whereas a dry seed exposed for a short time to a much higher temperature will germinate (Art. 60).

56. Absorption of Water by Seeds.—It is easy to show by experiments that seeds absorb a very large amount of water, and that the water enters more rapidly through the micropyle than through the seed-coat itself. The micropyle is a canal leading into the cavity of the seed, and water entering here passes round the edge of the cotyledons, into the space between them, and into the radicle-pocket. Water also enters by ***osmosis*** (see Art. 13) through the seed-coat, and at the same time part of the matter contained in the young plant passes out, in solution, into the water. This substance which escapes from the seed is largely 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.

Exp. 1.—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.

Exp. 2.—Weigh a number of dry Beans and fix them into notches cut round half the circumference of a flat cork; about half of each seed should dip into the water, with the scar end downwards. Weigh an equal number of seeds and fix them into the rest of the edge of the cork, but with the scar end upwards, well out of the water. After a few days remove each lot of seeds separately, wipe them dry, weigh, and compare.

Exp. 3.—In an experiment 25 Broad Bean seeds were found to weigh 61·8 grammes; after being kept at 45° C. in a drying oven for two hours they weighed 56·2 grammes, and as this weight was again found on weighing half an hour later it was taken as the actual dry weight of the seeds. The seeds were placed in water, which was renewed every day, and after five days the soaked seeds were dried at 45° C. till they showed a steady weight of 51·3 grammes. This means that nearly 10 per cent. of the solid matter of the seeds had diffused into the water.

57. 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 simply depriving the seeds of air.

Exp. 1.—Drop some seeds into a glass jar or wide-necked bottle, fill up with water, and cork tightly. As a control, put some soaked seeds into a similar jar, leaving it open and adding a little water each day to prevent the seeds from becoming dry, but not enough to cover them. Ordinary tap water contains dissolved air, but as a rule seeds immersed in it in a corked bottle do not germinate; to make quite sure that no air reaches the seeds the water should be previously boiled to expel the dissolved air, and the cork sealed air-tight with vaseline or plasticine. To hold the seeds down fix them into a spiral coil of wire, made by winding iron or brass wire round a tube or a stick.

Exp. 2.—The preceding experiment shows that air is essential for germination; this can be proved in various other ways. Let us confine some seeds in closed vessels containing different *quantities* of air, and compare the results. Take four cylindrical glass jars, all of the same size, and provided with well-fitting corks. 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 times as much sand, and therefore only a quarter as much air, as the first. In each jar now place an equal number of soaked Beans (or Peas, or other seeds), cork tightly, and seal with plasticine and vaseline. 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): note the white precipitate indicating the presence of carbon dioxide.

58. Respiration of Germinating Seeds.—The preceding experiment shows 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. Again, since respiration is a process of oxidation, just as burning is, if it takes place vigorously we should be able to show that germinating seeds give out heat.

Exp. 1.—Put together the simple apparatus shown in Fig. 33. Half fill a glass jar 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 small jar or 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.

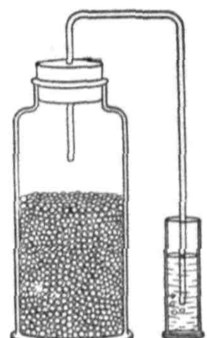


Fig. 33.

Exp. 2.—Use the same apparatus, but this time push down among the Peas a test-tube containing caustic potash solution, and place in the outside jar some water coloured with red ink. The potash solution absorbs the carbon dioxide given out by the seeds, and the coloured water rises in the tube as the volume of the air in the apparatus diminishes.

Exp. 3.—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 in the case of the germinating seeds.

59. Warmth required for Germination.—We know from common experience that plants require a certain amount of heat in order to grow, and that this amount differs considerably in different plants. This applies to germination, which is a process of growth, and there is for each species of plant a certain temperature at which germination is most rapid and which ensures the highest percentage of plants from the seeds sown. The temperature below which germination does not begin is called the minimum, that above which there is no germination is the maximum, while the most favourable temperature is the optimum. In general, the temperatures at which the seeds of most wild and cultivated plants grow best out-of-doors in our climate lie between 18° C. and 35° C. It is important to note the variation in minimum germination temperature in plants whose germination we wish to study. For instance, Cress will begin to grow at 2° C.; Wheat, Mustard, Broad Bean at about 4° C.; Scarlet Runner and Maize at 8° or 9° C.; Marrow at about 14° C.; while the Date requires a considerably higher temperature before germination will begin.

Exp. 1.—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, which is a bad conductor of heat.

Exp. 2.—Another method is to use two boxes as in the preceding experiment, 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.

Exp. 3.—In winter and spring the minimum temperature for germination should be determined for the seeds of different plants. 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.

60. Effects of Heat and of Cold on Seeds.—When a seed is exposed for a few hours to a moderately high temperature, the water it contained is driven off and the young plant is killed (we can only tell whether a seed is alive or not by finding out whether it will germinate when exposed to suitable conditions). But to determine the effect of heat itself we must expose the "dry" seed to high temperatures for a short time, not long enough to cause the loss of the water which it contains.

Exp. 1.—Place in a small muslin bag a dry bean and a bean that has soaked for two days, and dip the bag into water which is boiling over a Bunsen or spirit lamp. Try several pairs of seeds in this way, keeping them in the boiling water for different times (1 minute, 2 minutes, etc.), then plant them in your germination jars or boxes, with a suitable label on the glass above or below each seed. We find that dry seeds can withstand high temperatures which are fatal to soaked seeds.

Exp. 2.—On placing dry and soaked seeds among ice or a freezing mixture, we find that the dry seeds can also resist low temperatures that kill soaked seeds. Dry seeds can germinate after being exposed for a long time to the most intense cold that can be obtained, while soaked seeds are often killed by exposure to the freezing temperature of water or a few degrees below this.

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

Exp. 1.—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.

Exp. 2.—A better plan is to keep the two lots 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.

We see that light is not required for germination, but that seedlings grown in darkness have small yellowish leaves instead of well developed green leaves. We shall return to this point later (Art. 90).

62. 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.

63. Growth of Seedlings in Light and in Darkness.—Experiments on the respiration of germinating seeds show that the seedling loses carbon, which is released in the form of carbon dioxide. To estimate this loss we must dry the seeds and the seedlings before weighing them, since the water present must not be taken into account. Does this loss in dry weight occur both in light and in darkness?

EXP.—Take about forty Beans as nearly alike in size 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. Divide the remaining seeds into two lots, *A* and *B*, as nearly equal as possible; weigh the two lots, and calculate their dry weight. Sow *A* in sifted garden soil in a box which is kept in darkness, *B* 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 other way), and dry the seedlings 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, *i.e.* the *dry weight*. Get a piece of squared paper, as in Fig. 34 (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 dry weight, and the height, of the seedlings grown in darkness.

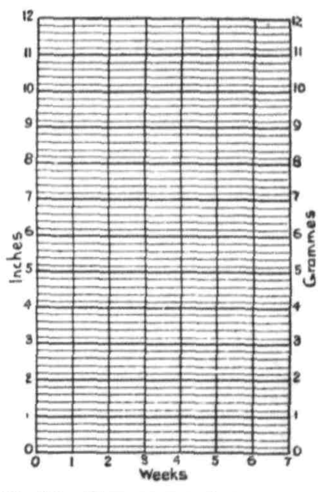


Fig. 34.—CHART ON WHICH TO PLOT THE CURVES OF HEIGHT AND DRY WEIGHT OF SEEDLINGS GROWN IN LIGHT AND IN DARKNESS.

64. Seeds contain Reserve 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 after a time increase in dry weight, and are therefore able not only to repair the loss due to respiration, but are also able 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. From the fact that seeds like those of Beans, Peas, Wheat, Maize, etc., are used as food by animals and by mankind, we know that seeds do contain organic (carbon-containing) substances; and in the case of Beans and Peas we infer from the size and thickness of the cotyledons that these are the storehouses of reserve food materials.

EXP. 1.—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*.

EXP. 2.—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.

EXP. 3.—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.

65. The Reserve Food Substances in Seeds.—The chief food substances contained in seeds are **proteins, starch,** and **oils.** Proteins are complex nitrogenous compounds, containing carbon, hydrogen, oxygen, nitrogen, sulphur, and in some cases phosphorus; they form the living substance (*protoplasm*) of both plants and animals, hence a supply of proteins is present in all seeds. Starch contains carbon, hydrogen, and oxygen, and belongs to a class of compounds called *carbohydrates* from the fact that the proportion by weight of hydrogen to oxygen is always the same as exists in water, namely 1 : 8. Oils are also made up of carbon, hydrogen, and oxygen, but the proportion of oxygen to hydrogen is smaller than in the carbohydrates; chemically, oils are compounds of glycerine with "fatty" acids.

All seeds contain proteins, and in addition usually also either starch or oils. Other reserve food substances also occur in seeds, as **cellulose,** a carbohydrate allied to starch; in the Date, for instance, the extreme hardness of the seed (stone) is due to the presence of a large amount of cellulose.

These reserve substances are either insoluble (oils, cellulose) or only slightly soluble (starch, some proteins) in water and in the sap contained in the tissue of the seed and seedling; even when slightly soluble in water, they are indiffusible, *i.e.* they cannot pass through the membranes of plant tissues, through which only water and soluble substances that are *diffusible* can pass. Therefore the greater part of the reserve food must be converted into substances which are soluble in water and also diffusible through membranes, so that they can be carried in solution through the membranes from the tissues of those parts of the plant in which the food is stored to those of the parts in which it is required for growth—*e.g.* the growing plumule and radicle.

There are various ways in which we can convert starch, proteins (most of which are insoluble in water), oils, and cellulose into soluble and diffusible substances. In the plant, as in animals, this conversion is brought about by the action of *ferments,* soluble substances present in the various digestive juices of animals and also found in germinating seeds.

In animals starch is changed into sugar by the ferment ptyalin in the saliva, and by a similar ferment in the pancreatic juice; proteins are changed into soluble peptones by the ferment pepsin in the gastric juice of the stomach, and also further digested into simpler substances by a ferment in the pancreatic juice; oils are acted upon partly by the bile, which causes the oil to separate into fine drops, but chiefly by a ferment in the pancreatic juice which splits up the oil into glycerine and a fatty acid; while in herbivorous animals there are ferments in the digestive juices which change cellulose into sugar.

The ferments found in plants—not only in seeds, but whenever and wherever food substances require digestion, or conversion into simpler and more soluble substances—are either identical with, or very similar to, those present in the digestive juices of animals, the products being also similar in each case.

Before testing seeds, or other parts of plants, for starch, proteins, etc., we should examine samples of these substances and thus learn how their presence can be detected in plants.

Exp. 1.—Shake a little powdered laundry starch in two test-tubes (*A*, *B*), each half full of cold water: the water becomes milky, owing to the suspended starch particles. Heat *A* to boiling for some time: the liquid becomes more or less clear, especially if only a small quantity of starch has been taken, hence starch is soluble in hot water; cool the tube under a running tap, and add a drop or two of iodine solution (iodine tincture diluted with water, or iodine dissolved in solution of potassium iodide): the liquid becomes blue. Note that the colour disappears on heating and reappears on cooling. The depth of the blue colour varies according to the strengths of the two solutions, but even a very dilute starch solution becomes blue with dilute iodine solution, hence this is a delicate test for starch. Now filter the liquid in *B*, test the filtrate with iodine, and note that starch is hardly soluble in cold water.

Exp. 2.—Boil an egg for four or five minutes. Pound up a bit of the clotted white (albumin) with soda-lime, put the mixture in a dry test-tube, and heat: ammonia is given off, and is detected by the smell, by the blueing of red litmus paper, and by the formation of white crystals on a drop of hydrochloric acid on the end of a glass rod held in the tube. This indicates the presence of nitrogen in the albumin. To show that sulphur is present heat a bit of the albumin in a test-tube, holding over the mouth a piece of lead acetate paper: the paper turns black, owing to the formation of sulphide of lead. To another piece of albumin add strong nitric acid—it becomes yellow; then add some ammonia—the colour deepens to orange.

Exp. 3.—Place drops of oil of turpentine and olive oil on different parts of a sheet of paper. In both cases a greasy stain is formed. The oil of turpentine soon disappears; the olive oil does not disappear. The former is a volatile oil, the latter a non-volatile oil. Soak the paper in a little alcohol for a few minutes: when the paper dries the stains due to the olive oil disappear.

Exp. 4.—Now apply these tests to seeds. *Proteins* turn brown with iodine solution, yellow to orange with ammonia and nitric acid; *starch* turns blue or violet or almost black with iodine solution; to test for *oils* fold the seeds in blotting-paper and crush between two flat stones (or by some other means), noting the greasy stain which dissolves in alcohol.

66. How the Seedling uses up its Stored Food.—We have now seen how the germinating seed digests the food materials stored in the seed. Directly germination begins, *i.e.* as soon as the seed has absorbed water and has been supplied with warmth and oxygen, ferments are produced which change the reserve foods into soluble substances which can diffuse through the membranes and reach the parts which are growing. These substances are then largely consumed by respiration, which breaks them down into carbon dioxide and water, but partly used to supply material for the formation of new tissue. When substances are oxidised energy is set free, and it is easy to discover that a seedling expends energy in different ways. The root and the shoot can overcome considerable resistance in their growth, while energy is also set free in the form of heat and in other ways.

When a seedling is grown in darkness it loses in dry weight, besides expending energy in exactly the same way as a seedling grown in light; and since the seedling dies when it has exhausted the supply of stored food, the time for which a seedling can last in darkness depends simply on the amount of this stored food.

If the food store is scanty, the seedling lasts only for a short time when grown in darkness, while seedlings with a large food store, as Beans, can grow for months in darkness.

Again, we shall see later that plants must be supplied with certain elements in the form of salts in order to grow well. The seed contains, in addition to proteins, starch, and other organic food materials, a supply of salts sufficient to enable it to germinate and grow for some time, as can be easily proved by supplying the seeds with distilled water. Here again the time during which the seedling can grow depends on the amount of stored material. While small seeds like Cress or Mustard can grow for some weeks when supplied with distilled water, those of Beans can grow for a long time, and, if in the light, can produce flowers and seeds, though the plants are much smaller than plants supplied with the necessary salts.

67. Energy supplied by Respiration.—We know that the radicle and plumule of a Bean seedling, for instance, must exert considerable force in growing through the soil. We can roughly measure the force exerted, and by calculation we can roughly determine the amount of energy that is set free by the oxidation of the carbon contained in the seed's store of reserve food.

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 proteins 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.

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 lb. 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.

68. Oak (Fig. 35).—In autumn get ripe acorns, also unripe ones still attached to the "cup." Notice the circular patch at the broad end; pull an acorn from its cup—the patch on the acorn is a *scar*. In a young acorn the narrow end bears a tuft of three projections – the *stigmas* of the pistil. Sometimes only the *style* which carried these stigmas remains on the ripe acorn as a stiff outgrowth. We see that the acorn is not a seed, but a *fruit*. The hard shell is not the seed-coat, but the *pericarp* or fruit-wall, corresponding to the shell of a Bean pod. Remove the shell and note that the contents readily split into two parts or lobes (*cotyledons*); pull these apart and note at the narrow end of one or other of the cotyledons a pointed body (*radicle*), and just above this the very small *plumule*.

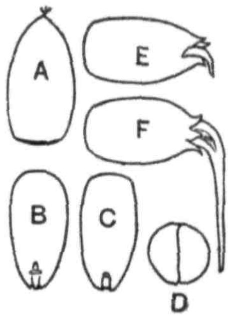


Fig. 35.—Germination of Oak.

The acorn thus contains a single seed, consisting of an embryo covered by a thin seed-coat. It answers to a Bean pod in which only one seed has ripened, and is an example of a dry one-seeded fruit (*achene*).

In germination the shell (pericarp) splits into several teeth at the narrow end, the root emerges, and the cotyledon stalks elongate so as to push out the young root and shoot, the latter growing up between the stalks. The cotyledons, which contain abundant starch, gradually shrivel within the pericarp.

69. Sunflower (Fig. 36).—Get "seeds" of this plant, and if possible Sunflower heads of different ages showing flowers and fruits. In this case, as in the Oak (acorn), the "seeds" are really dry one-seeded fruits (achenes). The Sunflower achene is attached to the plant by its narrow end, and the hard shell is the pericarp; the upper parts of the flower fall off and leave only the fertilised ovary, *i.e.* the achene.

Soak some achenes in water for a day or two and note that the shell splits along the edge into two pieces to let the root emerge from the pointed end. The seed is attached by a short stalk to the pointed part of the achene; it has a thin coat and contains an embryo (note the two flat cotyledons—root, shoot). The cotyledons come above ground and turn green. The stalk (hypocotyl) which carries them up is at first bent downwards at the top. This hook or loop is seen in very many seedlings, whether the cotyledons stay below or come up; in the former case it is the part above the cotyledons that is hooked, in the latter case it is the part below them (hypocotyl). Test the cut surface of a Sunflower cotyledon with iodine solution: it gives a brown stain. No starch is present, the reserve food consisting of oil and proteins.

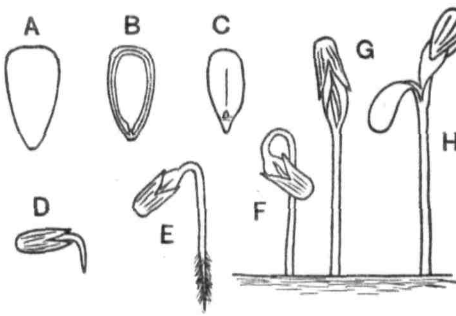


Fig. 36.—SUNFLOWER.

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

70. Maize (Fig. 37).—Get some Maize "seeds," also a Maize "cob," from a corn-merchant. A glance at the cob, on whose axis the grains are crowded, shows that the narrow end of the grain is the fixed end, while the examination of a young cob shows that the thick end at first bears a long feathery outgrowth—the *stigma*. The ripe grain of Maize is therefore an *achene*; the stigma has fallen off and left no trace.

On the outside of the grain notice (1) the withered remains of the stalk at the narrow end, and (2) the oval patch on one side. On this patch there are two ridges; one occupies the upper part of the patch (*i.e.* towards broad end of grain), the other the lower end, and both are in the same straight line drawn longitudinally through the middle of the patch (Fig. 37, B).

With a knife catch at the pointed end of the grain and tear off the thin transparent tough skin. The two ridges are outgrowths from the patch, *i.e.* appendages which are fixed to the middle of the patch. Lay a grain on the table with the patch-bearing side uppermost and make a clean slice down the middle of the patch. The two appendages are attached to a fairly thick structure which projects deeply into the grain and runs across its interior (Fig. 37, c).

The lower appendage is a solid peg, while the upper one separates into layers. The upper appendage is the young **shoot,** bearing leaves, the lower one is the young **root.** The shield-like oval body to which these appendages are attached recalls the appearance of a Bean embryo from which one of the cotyledons has been removed ; it is the **cotyledon** of the Maize embryo. Some botanists prefer not to call this body (found in the grains of Grasses and Cereals) the cotyledon, but name it the *scutellum* (shield). If the scutellum (or cotyledon), the root, and the shoot together make up the young plant, what is the *rest* of the seed?

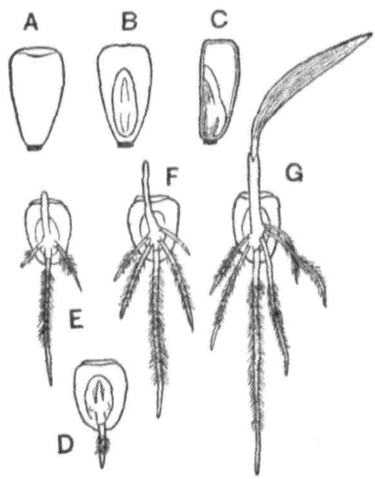


Fig. 37.—GERMINATION OF MAIZE.

Smear the cut surface (longitudinal section) with iodine solution. This produces a vivid contrast between the young plant and the rest of the seed: the former is stained brown (protein), the latter blue-black (starch), the two parts being separated by a sharp line.

The starch-containing part of the Maize grain is something which is not represented in any of the seeds we have so far examined. It therefore deserves a special name, and it is called the **endosperm.**

When Maize germinates the young root appears first and grows vertically downwards. It bears rootlets, but it does not (as in Bean, Pea, etc.) give rise to the whole root system of the plant. Examine and sketch seedlings of different ages; in one showing the first green foliage-leaf study (1) the root system, (2) the shoot system.

(1) Note that two, three, or more roots have grown out from the base of the young shoot. Examine the bases of the roots by means of a lens, and observe in each case the minute sheath out of which the root appears to grow; this sheath is produced by the newly formed root bursting through the tissue of the parent axis.

(2) Note the tubular sheath through the burst apex of which the first foliage-leaf has made its appearance. Compare this with earlier stages of germination, especially noting that at first the sheath is closed at the tip; that for some time—certainly for so long as it remains under the soil—it grows at the same rate as the oldest leaf of the enclosed bud, but that sooner or later it gets burst by the rapidly elongating foliage-leaf after the tip of the cone is carried well out into the air.

71. Wheat resembles Maize in the general structure of the grain and the mode of germination, but there are several differences in details which should be carefully noted.

In a soaked Wheat grain note the deep furrow running along one side, the small projecting body (embryo) at one end of the opposite side, and the tuft of hairs at the other end. Sketch each side of the grain. With a needle remove the coat of the grain over the embryo, so as to see the radicle and plumule, behind which lies the shield-like cotyledon. Slice the grain longitudinally, cutting down the groove, and sketch what you see (use a lens). Touch the cut surface with iodine solution: the endosperm turns nearly black, the embryo brown. With a needle raise the radicle and plumule from the cotyledon; in the plumule note the young leaves, which can be separated by using the needle.

Sketch stages in germination, noting the arrangement of the foliage-leaves in two rows, their grass-like form, the parallel main veins joined by delicate transverse veins. In a seedling showing the second green leaf examine the root system and shoot system, as described for Maize. Notice the shrunken appearance of the grain, which is now soft and pulpy. Squeeze the grain and notice the milky or watery fluid which escapes; the milkiness is due to the presence of the minute starch grains. Taste the fluid: it contains sugar. Tear open the grain, wipe away the pulpy contents, and notice the white "shield" (cotyledon), which secretes the diastase required for the conversion of the starch into sugar and through which the sugar passes to the growing parts of the root and shoot systems.

72. Endospermic and Non-endospermic Seeds.—In some seeds the seed-coat is completely filled by the embryo (Beans, Peas, etc.) and the reserve food is stored in the embryo, usually in its cotyledons. In other seeds we find an additional part or region, called the endosperm, which contains the reserve food, and which may either surround the embryo (Castor Oil), or lie alongside of it (Maize, Wheat), or lie in the middle of the seed with the embryo curved around it (Buckwheat, Onion).

A seed which has endosperm is called an *albuminous* or *endospermic* seed, one without endosperm is called an *exalbuminous* or *non-endospermic* seed. The difference between the two kinds of seeds is simply that in the first kind the food store is contained in the embryo itself, in the cotyledons (with a few exceptions which we need not trouble about), while in the second kind the food store is contained in a separate region of the seed outside of the embryo altogether. The word endosperm must not be mistaken as meaning food of one or more kinds; all seeds contain food, whether this be stored in the embryo itself or in the endosperm. The word "albumen," sometimes used instead of "endosperm," is still more apt to cause confusion, for this word is also applied to the white of egg and similar substances. Such substances are found in all seeds, whether in the embryo or the endosperm.

The main point is that the endosperm is simply a region, or tissue, which is found in some seeds along with the embryo, and which contains the stored food. When this region or tissue is not present the stored food is contained in the embryo itself, usually in its cotyledons.

73. 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 are "hypogeal," remaining below the ground, or on the surface, and simply yield up the food to the growing root and shoot. In *most* non-endospermic plants, however, the cotyledons are carried up into the air and become green, and like all green leaves *manufacture* food. 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).

74. Further Work on Seeds and Seedlings should be carried out as time permits. In each case soak, dissect (remove coat, cut sections), examine with a lens where the parts are small, and raise seedlings as already described; where the seed itself is small, or parts like the plumule are difficult to see, much can be learnt of the structure of the seed by examining different stages in germination. Test the seeds for starch, proteins, and oil as already described. The seedlings will serve as material for various experiments in plant physiology and for examining the structure of root-hairs, rootlets, etc.

Note that in most *non-endospermic seeds* (Linseed, Mustard, Cress, Radish, Turnip, etc.) the cotyledons are *epigeal*, being carried up by the elongation of the hypocotyl and becoming green and spread out; note the form of the cotyledons in each case, *e.g.* two-lobed in Mustard (Fig. 42), three-lobed in Cress, but in most cases simple in form. Also note that the earliest foliage-leaves are usually simpler in form than the later ones; but there are some exceptions to this rule—*e.g.* the early leaves of Gorse seedlings are three-lobed, while the later ones are simple and narrow; in "Nasturtium" (Tropaeolum) the early foliage-leaves are often lobed at the edge and have the stalk inserted at the margin (as in most leaves), but in the later leaves the blade is rounded and the stalk is inserted at about the middle of the lower surface (peltate leaf).

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.

As additional examples of *endospermic seeds* examine Castor Oil, Date, Onion, Buckwheat, Oat, Barley. The two last are very similar to Wheat. In Castor Oil note the spongy mass (aril) at the micropyle end of the seed; the hard seed-coat; the white oily endosperm; the embryo in the middle of the endosperm, with two thin flat cotyledons, radicle, and small plumule—dissect the seed and cut it across at different points to see these parts, which are more easily seen after germination: in the seedling note that the hypocotyl elongates, that the cotyledons remain inside the seed-coat until the endosperm has been reduced to a thin papery layer, and that the cotyledons then emerge and act as foliage-leaves.

In the Date seed (stone) note the deep groove on side; scrape the surface on the opposite side, and at the middle note the small embryo embedded in the stone (endosperm); cut across the stone at this point to see the plug-like form of the embryo; in seedlings (raised in a warm place) note that the hypocotyl grows out as a stalk with a swelling at the free end, from which the radicle grows downwards while the plumule grows up out of a sheath; open the stone, which softens as germination proceeds, and note the extent to which the cotyledon has enlarged while digesting and absorbing the reserve food (cellulose).

In a seedling of Onion, before the embryo has finally withdrawn its cotyledon from the seed, note the root, marked off by a slight swelling from the base of the hollow cotyledon whose tip is still inside the seed; remove the seed-coat and note the colourless end of the cotyledon coiled within the seed; in older specimens note the withering of the tip of the cotyledon, and split open the hollow sheath at its base to see the plumule.

CHAPTER VIII.

NUTRITION, RESPIRATION, TRANSPIRATION.

75. Questions arising from Observations on Seedlings.—Our work on the germination of seeds raises many questions. We have obtained, by making experiments, answers to those questions which relate to the external conditions necessary for germination to take place; to the need for the seed itself to remain alive but dormant during the resting season and to have a store of food for at any rate the early stages in germination; and to the nature of the stored food, and the way in which it is used up to supply the material and energy required for growth. We have seen that germination begins directly the seed has absorbed water and has been supplied with warmth and oxygen; even before the seed shows outward signs of growth beyond the swelling due to absorption of water, chemical changes take place—ferments convert the insoluble and indiffusible reserve food into soluble and diffusible materials, and these are oxidised in the process of respiration. It is more difficult to say when germination ends, for the seedling grows on and becomes in time an adult plant.

We have now to enquire how this further growth proceeds, and how the plant obtains food when it has used up that stored in the seed. We shall deal with the food question first, *i.e.* with the *nutrition* of the plant, for we have seen that for the growth of the seedling a supply of food is essential, and this may be expected to apply also to later growth.

76. The Sources of Plant Food.—Many parts of plants besides seeds store up food for a resting season, and when active growth is resumed use this stored food in exactly the same way that a seedling does. For instance, a Potato tuber contains starch and proteins, besides water and salts, and when the tuber sprouts the starch and proteins are digested and supply soluble and diffusible food at the expense of which the buds ("eyes") of the tuber grow out to form shoots, from which roots arise. The fact that the tuber bears buds (each in the axil of a scale-leaf) shows that it is not a root but the swollen end of an underground branch of the stem; while to call the tuber a "seed," simply because it can be planted either entire or in pieces (each piece having one or more "eyes") and yields new Potato plants, is of course wrong. Just as a seed with a large amount of stored food, *e.g.* Broad Bean, can live and grow for a considerable time at the expense of this food, so a Potato tuber can produce shoots even when grown in the air, either in darkness or light, and without any supply of water—unlike the seed, the tuber contains a good deal of water.

As in the case of a germinating seed, a Potato-tuber allowed to sprout in darkness loses in dry weight, and if kept in darkness the plant eventually dies without forming flowers and without producing normal green leaves. Hence one at any rate of the conditions required for the formation of new food-materials, of green leaves, and of flowers is that the plant should be supplied with *light*.

Another essential condition is a supply of *water*, without which growth is impossible. But we have seen that seedlings grow badly in *pure* (distilled) water, so that the water supplied to plants must contain dissolved substances. In ordinary land plants these substances are contained in the soil; there are some plants which grow submerged in the water of ponds and have no roots but float freely in the water—such plants must be able to obtain the dissolved substances they require from the water itself, and we know that this water contains dissolved *salts*.

Before enquiring further into these matters, it is interesting to notice what was believed not so very long ago concerning the way in which plants obtain their food. Until about the middle of the seventeenth century it was generally thought that plants received all their food from the soil, and in a state ready for immediate use—that is, that the soil itself contained all the substances found in plants, even those which gave the various tastes and odours of different plants, and that all the plant had to do was to absorb these substances by means of its roots.

It was therefore believed that the root was the most important part of the plant, serving to suck in food from the soil like a sponge; that plants, like animals, had a system of veins acting as food-passages to carry the ready-made food from the root to the stem and leaves and flowers; and that the leaves served only for the protection of the buds and flowers from cold or heat or strong sunlight. All this was quite natural at a time when so little was known about Chemistry, and indeed even intelligent people nowadays who know little or nothing of Chemistry would probably see nothing wrong in such ideas.

At last, however, even before the foundation of modern Chemistry, men began to doubt the truth of these ideas, and the credit of making the first experiment in the physiology of plants belongs to J. B. van Helmont (1577-1644), of Brussels, a leading representative of the Chemistry of his day. He believed that all things consist of air and water, but he tested his theory by making an experiment, about 1630. He thoroughly dried some soil, placed 100 lb. of the dry soil in a pot, and planted in it a Willow branch weighing 5 lb., covering the soil to protect it from dust and watering it daily with rain-water. In five years the Willow had grown into a large plant, weighing 169 lb., but the soil when again dried showed a loss of only 2 oz.

Van Helmont concluded that the increase in weight of the plant had been gained entirely from the water, and that all the materials in the plant, though distinct from water, nevertheless came from it. This conclusion was wrong, for we now know that water can exist only in three forms, and that in all three it is the same chemical compound; but at any rate it disproved the older theory.

77. Essential Elements; Water Culture.—There are two ways in which we can study the chemical composition of a plant —(1) we may dry the plant and burn it, in order to find out which chemical *elements* pass off during burning and which remain behind in the ash; (2) we may apply tests for the various chemical *compounds* present, such as proteins, starch, sugar, oils, as we have done in the case of seeds.

On burning a plant and analysing the gases given off and the ash left behind, we find that the following chemical elements are present in all plants: carbon, oxygen, hydrogen, nitrogen, sulphur, phosphorus, calcium, magnesium, potassium, iron, sodium, silicon, chlorine; other elements are often present, at any rate in traces. Of these elements, the first six actually enter into the composition of the living substance (protoplasm) of the plant, which is made up of proteins. It is obvious that these six elements are essential for the normal growth of plants. In order to find out which of the other elements found regularly in plants are really essential, we must grow the plant with its roots in a *culture solution* of known composition; we must also supply the plant with *air*, which consists of oxygen and nitrogen, with a small proportion of carbon dioxide; and to enable it to grow healthily we must place it in the *light*.

By trying culture solutions containing different salts it has been found that a plant will only grow in a healthy manner if the elements present include, besides the *hydrogen* and *oxygen* of the water itself, *nitrogen, sulphur, phosphorus, calcium, magnesium, potassium,* and *iron.* With suitable precautions a plant can be successfully grown in a solution containing only these nine elements; if any one of these elements be omitted, the plant grows less healthily, and indeed dies as soon as it has used up any store of the element in question which it contained at the beginning. This method of growing plants is called *water culture,* since the solution consists of salts dissolved in water.

The second method of plant-analysis is much more difficult to carry out, for in addition to proteins, peptone, starch, sugars, and other easily recognised compounds, plants contain a very large number of organic substances. But each of these contains carbon, together with more or fewer of the other elements which we find by the water-culture method to be essential for plant growth.

78. Experiments with a complete Culture Solution.—Get some large glass jars, each holding at least a quart, for water-culture experiments. The simplest complete solution consists of 2 grammes of calcium nitrate and 0·5 gramme each of potassium nitrate, magnesium sulphate, and potassium phosphate, with a drop or two of iron phosphate solution, 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.

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. 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).

Darken the roots by covering the jars with black cloth or paper; add water each day to replace that lost by evaporation (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 few days with a bicycle-pump or a syringe.

79. 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, omit potassium nitrate, and use calcium phosphate instead of potassium phosphate. Deprive others of calcium by omitting the calcium nitrate; of phosphorus by omitting the potassium phospate and using some other iron salt than phosphate; of magnesium by using calcium sulphate in place of magnesium sulphate; of sulphur by using magnesium nitrate instead of the sulphate; of nitrogen by using calcium and potassium sulphates in place of calcium and potassium nitrates; of iron by omitting the iron salt (which should be added in all other cases).

80. Absorption of Carbon Dioxide by Green Leaves.—A complete culture solution contains no carbon; the plant would grow neither better nor worse if we added carbon in any form (as dissolved carbon dioxide or as carbonates, for instance) to the water containing the nine elements supplied to the root. But since carbon is present in all organic compounds and forms a large proportion (usually about one half) of the dry substance of plants, the plant must be supplied with this element. The carbon is obtained from the air, which contains carbon dioxide. We may now enquire which parts of the plant absorb carbon dioxide from the air.

Exp.—A rough idea may be obtained by taking a number of bottles with tightly fitting corks, and placing in them (1) green leaves freshly picked from a plant, (2) pieces of fresh stem, (3) pieces of fresh root. Breathe several times into each jar, corking it tightly; set up a duplicate jar in each case, so that of each pair of jars one is exposed to bright light and the other kept in darkness. After some hours, open the jars and test for carbon dioxide by means of lime-water. Note that carbon dioxide is still present in every jar except the one containing leaves which was exposed to light—if the exposure to light has been long enough all the carbon dioxide in this jar will have disappeared.

81. The Presence of Starch in Green Leaves Exposed to Light.—The preceding rough experiment proves that only the *green* organs of a plant—in most cases the foliage-leaves—absorb the carbon dioxide of the atmosphere, and this absorption only takes place in the *light*. What becomes of this absorbed carbon dioxide? A good way in which to attempt an answer to this question is to apply tests for organic compounds (such as starch, proteins, oils, which we found in seeds) to the green organs. Proteins are necessarily present in *all* parts of plants, but we saw that some seeds contained starch while others contained oil. The iodine test for *starch* is particularly easy to apply, and the depth of the colour produced indicates roughly the abundance or otherwise of this substance. In order to test leaves for starch we must first remove the green colour.

EXP.—Boil in water some leaves taken from a plant with thin flat leaves which has been growing in the light for several hours on a bright day. 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, as "Nasturtium" (Tropaeolum) or Primrose, much more quickly. 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 only stains the leaf brownish.

82. Disappearance of Starch from Leaves in Darkness.—During germination the starch present in seeds disappears, and is converted into sugar. If we test with iodine the foliage-leaves of a Bean seedling which has grown in darkness we find that starch is present, but this must simply mean that some of the sugar has been changed back into starch after having been carried in solution from the cotyledons to the foliage-leaves.

Similarly, if we find starch in the leaves of Potato shoots which have sprouted from a tuber grown in darkness, this starch must have got there in the same way, its real source being the starch originally stored in the tuber. To simplify our enquiry we may either use a plant which is not simply growing (like a Bean seedling or a sprouting Potato) at the expense of stored food, or we may make experiments with single leaves removed from the plant and set with their stalks dipping into water.

EXP.—Cut off a leaf of the Nasturtium or Primrose plant used in the preceding experiment, and place it with its stalk dipping into water in a bottle. We have already found starch in the leaves, but to make sure cut out a piece (about one quarter) of this particular leaf and test it for starch. Then set the leaf in darkness, and next day cut off another piece and test for starch: much of the starch will have disappeared. Repeat this next day: the leaf will probably now give only a brownish colour with iodine, the starch having practically or entirely disappeared. Exactly the same is found if instead of single leaves we use a potted plant or a cut shoot, and test different leaves instead of pieces of the same leaf; in two days the leaves kept in darkness have become free from starch.

Now place in the light the leaves from which pieces have been cut, or the entire plant or cut shoot, and after some hours test for starch. The results show that starch appears in leaves exposed to light, but disappears from leaves kept in darkness.

83. Carbon Dioxide Essential for Appearance of Starch in Leaves.—The results of the preceding experiment do not in themselves prove conclusively that starch is *manufactured* by the green leaf—the starch which appeared in the light *might* have come from the sugar into which the starch found in leaves exposed to light is converted when the leaf is placed in darkness. We have seen, however, by a rough experiment (Art. 80), that carbon dioxide is only absorbed by green parts and only by these parts when they are exposed to light. Let us try the effect of depriving the air around a leaf, or part of a leaf, of carbon dioxide.

Exp. 1.—Take two basins, two large equal-sized bell-jars, two narrow-necked bottles or flasks of water, and two "Nasturtium" leaves which have been kept in darkness for two days. Place each leaf in its bottle so that the stalk dips into the water while the blade rests on the neck of the bottle; set the bottle in the basin, and pour about half an inch of water into each basin. Into one basin place, along with the bottle containing the leaf, a wide-mouthed jar or a saucer containing strong caustic potash solution; cover each basin with the bell-jar, and set the two pieces of apparatus in the light. The two leaves are under exactly the same conditions except that in one case the air in the bell-jar is ordinary air while that in the other is deprived of carbon dioxide. After some hours test the leaves for starch. The result will prove that starch is not formed in the absence of carbon dioxide.

EXP. 2.—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 freshly made lime-water or (better) baryta-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. 38). 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.

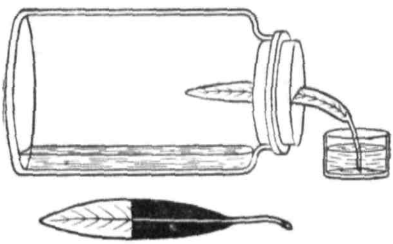


Fig. 38.—EXPERIMENT TO ASCERTAIN WHETHER CARBON DIOXIDE IS ESSENTIAL FOR PHOTOSYNTHESIS.

84. The Green Leaf gains in Dry Weight when Carbon Dioxide is absorbed and Starch appears.—The preceding experiments prove that when a green leaf has been kept in darkness until the starch originally present in it has disappeared, starch appears again only when the leaf, besides being exposed to light, is supplied with carbon dioxide. This fact suggests that carbon dioxide has been absorbed by the leaf and is concerned in some way with the appearance of starch in the leaf. If so, we should expect to find that the dry weight of the leaf is increased at the close of a sunny day or after some hours of exposure to light, that it decreases during the night or after some hours of exposure to darkness, increasing again on exposure to light, and so on. It is easy to find out whether this actually happens.

For the weighing experiments above suggested we should use plants with large leaves, *e.g.* Sunflower or "Nasturtium," and as the water present in leaves may vary considerably we should dry the leaves before weighing them. We must also, of course, compare equal areas of leaf taken (1) at about 7 a.m. on a warm sunny day, (2) at about 5 p.m. the same day, and so on for two or three days, in order to get good results. If potted plants are used, we can place them in darkness from late afternoon of one day, when we have picked off one batch of leaves, until a convenient time next morning, when we pick off the next batch before setting the plant in the light again.

EXP. 1.—The simplest plan, for a single day's (morning and evening) comparison, is to use a Sunflower plant, or other plant with fairly large and simple leaves (the parts of the blade on each side of the midrib nearly equal in area); for the morning weighing we cut each leaf longitudinally close to the midrib, dry the batch of half-leaves and find their dry weight, then cut off the remaining half-leaves in the evening and treat them in the same way.

EXP. 2.—A more instructive and convincing method is to compare small pieces cut from the same leaves day by day for a few successive days; so long as the midrib is not cut through, this treatment does not injure the leaf. Starting from the end of the leaf, we clip out a piece of the blade, lay it on a sheet of thick paper, trace its outline on the paper, then cut out the paper pattern of the leaf-piece and weigh it; we do the same with each successive morning and evening piece cut from the leaf, and from the weights of the paper patterns (which are proportional to the area of the leaf) we can compare the successive pieces of leaf and calculate the percentage increase or decrease of dry weight.

85. Effect of Starch-making on the Atmosphere around the Plant.—From the preceding experiments we see that when a plant is exposed to the light its leaves absorb carbon dioxide grown in darkness loses in dry weight, the loss being largely a loss of carbon owing to a process of oxidation (respiration), carbon dioxide being set free and oxygen absorbed; while a plant grown in light gains in dry weight, the gain being largely a gain of carbon, which is absorbed as carbon dioxide, oxygen being set free. We know that when starch is burned in the air the products of combustion are carbon dioxide and water, this also being a process of oxidation; also that when carbon is burned in a given volume of oxygen the carbon dioxide produced occupies the same volume.

These facts suggest that starch is produced in green leaves exposed to light by a process in which carbon dioxide is made to combine with water. Instead of a breaking-down process, we thus have a building-up or synthetic process, and since this takes place only in the light it is called Photosynthesis.

It is not correct to call the process "starch-making" as we have done up to now, for although starch is very often produced this is not always the case: some plants when absorbing carbon dioxide and gaining in dry weight do not produce any starch, but in such cases sugars are usually formed. Even when starch is produced in the leaf it is merely stored there for a time, as we have seen in our experiments showing that this substance disappears from leaves in darkness.

Photosynthesis is a complicated process, taking place in a series of steps, or stages, but in most cases sugars are formed before starch appears (if it appears at all), and evidently part of the soluble sugar is changed into insoluble starch in order that the process may go on continuously and not be brought to a standstill by the accumulation of sugar as a strong solution in the leaf-cells.

87. Further Experiments on Photosynthesis.—The fact that starch is produced in the leaves of many plants as a product of photosynthesis makes it easy to find out the various conditions required for this process; while a still simpler way of telling whether or not photosynthesis is going on is afforded by the giving off of bubbles by water plants—the faster the rate of bubbling the more vigorously is photosynthesis proceeding. In all cases we begin with starch-free leaves, by keeping the plant in darkness for a day or two; and we have seen that single cut-off leaves may be used instead of entire plants for experiments.

EXP. 1. *How Air enters a Leaf.*—We have previously (Art. 50) used a simple method for proving the presence of air within a seed and of a pore in the seed-coat—namely, by placing the seed in hot water and observing the escape of bubbles. Dip the leaves of various plants into very hot (just boiled) water in a warmed tumbler, and note the expulsion of bubbles.

In many leaves the bubbles appear only on the lower surface; in others they appear on both sides but more abundantly on the lower; in some marsh plants they are more abundant on the upper surface; while in floating leaves like those of Water Lily or of Common Pondweed (Potamogeton natans) they are confined to the upper surface. In these floating leaves, and in those of various other water and marsh plants, the air-spaces in the blade and stalk are large enough to be seen with the naked eye, and we can easily blow air through the stalk, holding the blade under water to see the bubbles coming from its surface. The pores in the skin of a leaf are called *stomata* (singular, *stoma*).

EXP. 2.—That the stomata form an entrance for air into the leaf can easily be shown by blocking them by means of wax or vaseline and seeing whether starch is formed. Select a plant whose leaves have the stomata only on the lower side; keep it in darkness until starch is absent; then treat different leaves as follows, expose to light, and after several hours test for starch: (1) smear the lower surface; (2) smear a circular patch of the leaf on both sides; (3) smear the upper surface; (4) smear both surfaces. Note that little or no starch is formed when air is excluded from the lower (stoma-bearing) surface of the leaf.

EXP. 3.—We have seen that submerged water plants produce starch. How do these plants obtain air? That they have no stomata is shown on dipping them into hot water. Cover the leaves and stem of a submerged water plant with vaseline, and note that it does not produce starch and does not give off bubbles: the submerged leaves must absorb air dissolved in the water. The leaves of land plants cannot do this; tie the stalks of the leaves of a land plant to a stone, sink them under water (a film of air covers the leaves, and should be removed by means of a camel-hair brush), and after exposure to light test for starch.

EXP. 4. *Warmth required for Photosynthesis.*—(1) Place a Primrose or "Nasturtium" leaf in a saucer or jar kept cold by pieces of ice, expose to light and after several hours test for starch. (2) Add ice to the water in a jar in which a water plant is growing exposed to light and giving off bubbles; note that the chilling of the water stops the bubbling.

EXP. 5. *Chlorophyll required for Photosynthesis.*—You may have noticed that the veins of Primrose or "Nasturtium" leaves, which are white or almost so, remain unstained even when the rest of the leaf is black with the iodine test for starch; this in itself shows that starch is formed only in the green parts of a leaf. Another proof is obtained by experimenting with variegated leaves which have yellowish or white strips or patches, *e.g.* varieties of Garden Geranium, Striped Maize: starch is formed only in the green parts of such leaves.

88. Conditions required for Photosynthesis.—To sum up, our various experiments have shown that the conditions required for photosynthesis are light of sufficient intensity, warmth, the presence of carbon dioxide in the air, and the presence of the green colouring matter (chlorophyll). That it is a vital process is easily shown by killing leaves, as by boiling them in water, and exposing them to light and the other conditions required: photosynthesis does not take place in dead leaves.

89. Chlorophyll.—We have seen that only the *green* parts of plants can make starch—so far as the plants we have experimented with are concerned, at any rate—from carbon dioxide and water. The green substance (chlorophyll) is contained in grains (chlorophyll-grains or **chloroplasts**) in the leaf-cells. Chlorophyll is not formed in plants kept in darkness (there are a few exceptions to this rule), nor in the complete absence of iron from the plant's food. If a plant is grown in darkness it assumes a pale yellowish, sickly appearance. This is due to the fact that a yellowish colouring matter (**etiolin**) is developed instead of chlorophyll. Such a plant is said to be *etiolated*. Etiolated plants have the internodes of the stem very much elongated, the leaves remain small and scaly, and there is a great development of soft tissue and a meagre formation of hard woody tissue.

A yellowish, sickly condition is also established if there is no *iron* in the food, the plastids being colourless or containing etiolin. This condition, due to the want of iron, is called the **chlorotic** condition. It is to be carefully distinguished from the etiolated condition due to the absence of light. As soon as the plant is supplied with a *weak* solution of an iron salt, even if it is only applied to the leaves, chlorophyll is developed.

Chlorophyll can be extracted by means of alcohol, ether, etc. 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. The green rays are absorbed to a much smaller extent than the rays in other parts of the spectrum. That is, the leaf reflects and transmits the green rays, which appear to play no part in photosynthesis, while it absorbs the useful rays which apparently provide the energy required for this process.

Exp. 1.—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.

Exp. 2.—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.

90. Conditions required for Formation of Chlorophyll.—It is easy to prove that *light* is essential for the production of chlorophyll. Sometimes one can get "chlorotic" plants by omitting *iron* from the culture solution in which seedlings are grown. What other conditions are necessary for chlorophyll-formation?

EXP. 1.—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 (1) a green tinge, due to formation of chlorophyll, may be developed in an hour, or less, in good light; (2) light too weak for photosynthesis is strong enough for the production of chlorophyll.

Exp. 2.—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. The results show that warmth is needed for the formation of chlorophyll.

Exp. 3.—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 etiolated seedlings of Bean or Pea in a jar and cover them 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.

91. 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 chlorophyll absorbs. 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, which take oxygen from the air and give out carbon dioxide.

When a plant is burnt, oxygen is consumed and mainly carbon dioxide and water produced, while the stored energy is liberated again almost entirely 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.

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, and almost the whole of this enters the leaf through the stomata. The leaf is an organ especially adapted for rapid gaseous exchange between the plant and the atmosphere.

Green plants when exposed to light and supplied with carbon dioxide can live, grow, and produce flowers and seed if they are also supplied with water and with the inorganic salts present in the soil. From these simple substances they are able to construct the whole of the food materials they require, and a large tree may produce some hundredweights of organic substance each year in this manner, although only a fraction of this food is used for constructive purposes or as storage material, the remainder being consumed in respiration.

92. Respiration.—Every living being, plant, or animal needs a continual supply of energy, without which, for example, neither growth nor active movement is possible. In the case of a machine, such as a steam-engine, this energy is derived from the burning of coal, the carbon of the coal being oxidised to carbon dioxide, and energy being liberated in the form of heat. Similar processes take place in all living beings, but here the combustion is less violent, so that the rise in temperature is never very great.

Like animals, all plants respire—that is, they absorb oxygen and exhale carbon dioxide—losing carbon during the process. Germinating seeds, growing fungi, opening buds, and opening flowers may respire about 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 hardly any supply of energy as compared with the more external ones.

Photosynthesis and respiration are therefore, 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. The former process is twenty or thirty times more active than the latter 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 daytime, 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. The following experiments illustrate these points:—

Exp. 1.—Place in a jar a bunch of roots, or some Carrots or Onions sliced in half, and after a day or two lower a lighted taper into the jar; what occurs?

Exp. 2.—Repeat the foregoing experiment with similar materials; place one jar in light, another in darkness. After a day or two pour in some lime-water or baryta-water, which will become quite milky, showing that carbon dioxide has been evolved in abundance. The same occurs when the bottles are exposed to bright light, as respiration continues almost unchecked.

Exp. 3.—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.

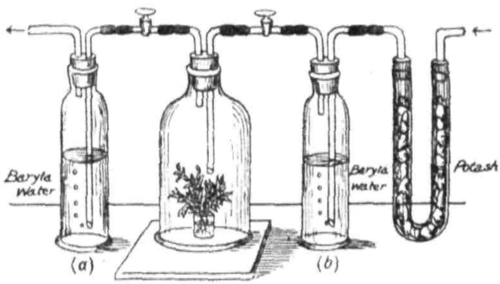


Fig. 39.

The arrows show the direction of the current of air, which is drawn through by attaching an "Aspirator" (see Fig. 17) at the left of the apparatus.

Exp. 4.—Place some green leaves in a glass jar (Fig. 39) through which a slow current of air is passed. This air is deprived of its carbon dioxide by the potash contained in the first tube, so that the lime-water or baryta-water in both (*a*) and (*b*) 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 (*a*) soon becomes turbid and milky.

93. 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*.

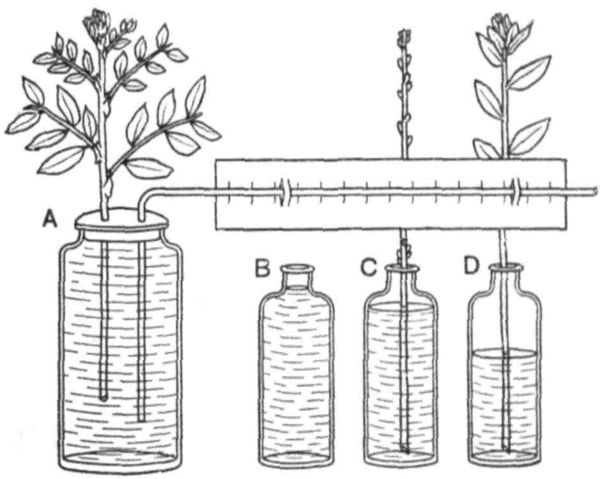


Fig. 40.—Apparatus for Study of Transpiration.

(N.B.—To save space *two* distinct experiments are represented in this diagram—A for Exp. 4 in Art. 93; B, C, D for Exp. 1 in Art. 93.)

Exp. 1.—Get three similar bottles full of water (Fig. 40, 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.

Exp. 2.—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.

Exp. 3.—Get any leaves with broad, thin blades and fairly long stalks—Lesser Celandine, Garden Geranium, etc. 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.

Exp. 4.—For experiments with cut shoots or even single leaves the apparatus sketched in Fig. 40, 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.

Exp. 5.—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 stomata are blocked (*a*) will be still green and fresh, while the others will be more or less withered and brown.

Exp. 6.—Get some **cobalt chloride** (or 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 them between two dry pieces of glass. Notice which surface of the leaf gives off most water-vapour, as shown by the change of colour.

94. Conditions affecting the Rate of Transpiration.—As might be expected, the rate of transpiration—that is, the rate at which water-vapour is given off into the air by the leaves—is controlled by the same atmospheric conditions as those concerned in simple evaporation of water from a free water-surface. It is hastened by warmth, by dryness (low relative humidity) of the air, and by air currents (wind). But it is also controlled by light, which has no influence on simple evaporation, for the stomata (through which all or practically all the water-vapour passes) close in darkness. Strictly speaking, the stomata do not become quite closed, for respiration still goes on in darkness, though transpiration is practically brought to a standstill. At night, however, the roots continue to absorb water from the soil, and many low-growing plants have special pores (water-stomata) on the tips or margins of the leaves, where the veins end, which serve to give off liquid water—this explains the drops of water often seen in the morning on the leaves of "Nasturtium," etc. A similar exudation of water, which has nothing to do with true transpiration, may be artificially induced by forcing water under pressure into a leafy shoot.

CHAPTER IX.

STRUCTURE OF LEAF, ROOT, AND STEM.

95. Structure of the Green Leaf.—Even without using a microscope we can learn a good deal concerning the structure of the foliage-leaf—for instance, that it is covered on both sides by a thin transparent skin layer (*epidermis*), and that the central portion (*mesophyll*) consists of green tissue which contains air spaces and is traversed by *veins* (see Art. 45, *e*).

If we examine with the microscope thin sections and other preparations we find that, like all parts of the plant, the leaf is made up of numerous closed chambers or *cells*, which differ greatly in different parts of the leaf. As shown in Fig. 41, in the upper part (*palisade tissue*) of the mesophyll the cells are vertically elongated with only narrow air spaces between them, while the cells of the lower part (*spongy tissue*) are star-shaped and therefore separated by wide air spaces; the cells of the mesophyll contain green grains (*chlorophyll grains* or *chloroplasts*); and each pore or *stoma* is bounded by two curved cells, called *guard cells*, which alone of all the epidermis cells contain chlorophyll grains and which have the power of changing in shape so as to open or close the pore of the stoma. The veins or vascular bundles of the leaf contain water-vessels and food-vessels like those in the stem (see Art. 97).

EXP. 1.—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 5 per cent. caustic potash solution for about ten minutes. The leaves become swollen, owing to the upper and lower skin-layers becoming separated from the middle tissue; prick the swollen leaf with a pin, and gently squeeze out the liquid which

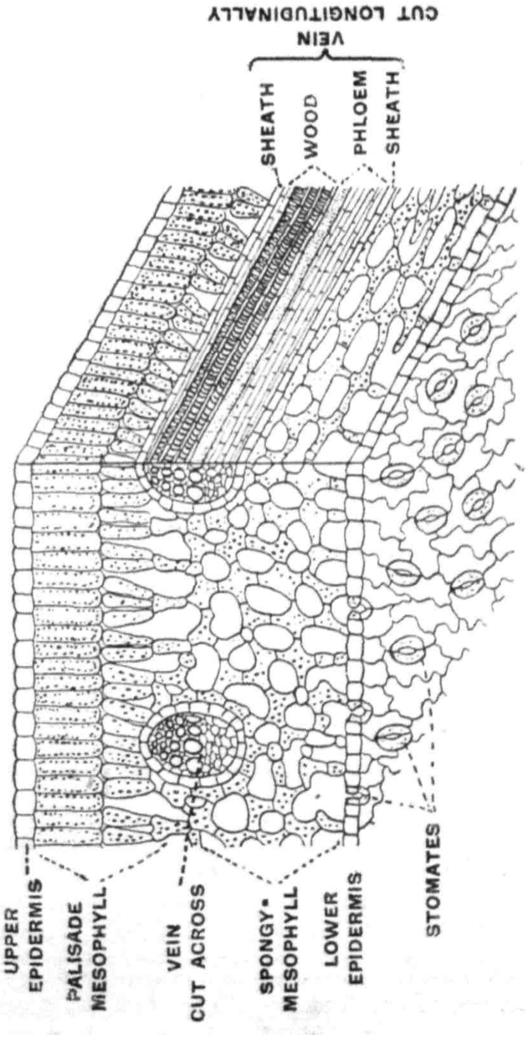


Fig. 41.

Partly diagrammatic representation of the structure of a foliage-leaf, showing transverse section, longitudinal section, and lower surface. See description in text.

has entered it. Hold the leaf under water in a saucer, and with scissors cut off a strip round the margin; the leaf is then readily separated 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 middle tissue or mesophyll, containing the veins, (3) the lower skin. 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 (stomata).

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 inside of the lower skin.

Exp. 2.—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 stomata (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 stoma 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 stoma. Now put a drop of water at one side and draw it through until the stoma opens again. Sketch the stoma opened and closed. The salt solution draws water out of the guard-cells, and then the stoma 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 stoma opens.

Exp. 3.—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 stomata contain starch. The starch-grains are very small and are formed inside the chlorophyll-grains.

96. Functions and Structure of the Root.—Besides serving to fix the plant in the soil, the root absorbs water and mineral salts from the soil-water. A fertile soil contains all the elements present in a water-culture solution (Art. 77), besides various others which are not essential for nutrition. Some of these are present in the form of soluble salts, but others have to be made soluble before they can be absorbed—for the root can only absorb substances in solution. Rain-water in percolating through the soil dissolves various substances which are insoluble in pure water, because of the action of carbonic acid (carbon dioxide dissolved in water), and it is easy to prove that the roots of plants can exert a solvent action on substances like chalk—this is partly due to the *formation* of acids as the old root-hairs die and decay, partly to the roots giving out carbon dioxide in their respiration.

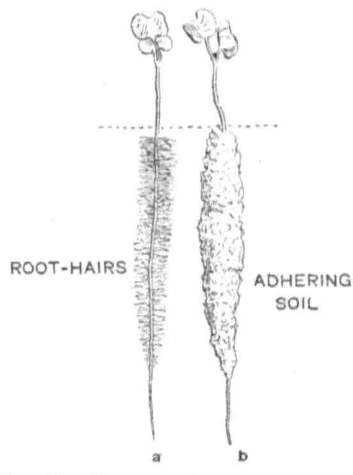


Fig. 42.—Mustard Seedlings grown in Sand.
(*a* has been gently rinsed in water.)

The absorbing area of the root is enormously increased by the *root-hairs*, which are long thread-like (tubular) outgrowths of the skin layer (epidermis), developed a short distance behind the growing tip of the root, soon dying away from the older parts. These hairs come into very close contact with the soil particles, so that when the root of a seedling is gently lifted from fine soil the latter adheres wherever root-hairs are present (Fig. 42).

Since the root-hairs contain cell-sap with dissolved sugar and other substances which "attract" water and are separated by a thin cell-wall from the soil-water, a dilute solution of salts, we have here the conditions under which osmosis (Art. 13) takes place, so that soil-water is constantly being absorbed by the root-hairs and passed on under pressure into the central tissue of the root, which contains vessels continuous with those in the vascular bundles of stem and leaves.

In a thin transverse section from the younger part of a root (Fig. 43) we find that the central (vascular) cylinder contains two kinds of conducting tubes, similar to those in the stem (Art. 97); the food-conducting tubes (sieve-tubes) are in bundles alternating with the bundles (wood-bundles) made up of the water-conducting tubes (vessels). All the organic food required for the growth of the root is, of course, manufactured in the green leaves, and part of this food is carried by means of the sieve-tubes to the cells of the root which are growing (or storing up food).

EXP. 1.—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?

EXP. 2.—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*?

EXP. 3.—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.

EXP. 4.—Grow seedlings in a layer of sawdust or soil resting on a slab of polished limestone. After a week or so, when

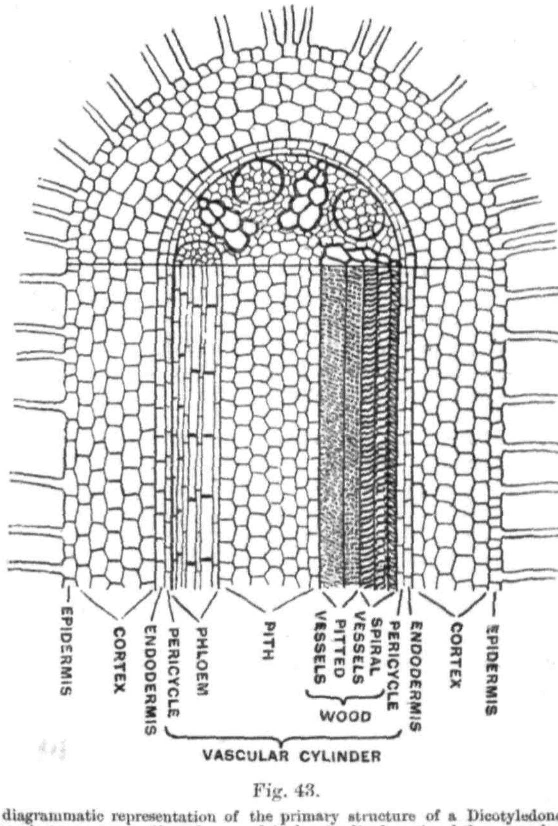


Fig. 43.

Partly diagrammatic representation of the primary structure of a Dicotyledonous root, shown in transverse section above and in longitudinal section below; one-half of the transverse section is shown—the root has five wood bundles and five phloem bundles in all. The numerous root-hairs arising from the epidermis (also called "piliferous layer") are cut short: these hairs are in reality long filaments, their length being several times the diameter of the young root.

the roots have reached the slab, remove the latter and examine the surface closely for the tracks eaten into it by the roots.

Exp. 5.—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.

Exp. 6.—Root-hairs are especially well seen on the roots of seedlings. 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.

Exp. 7.—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 from outside.

Exp. 8.—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 on the growing-point, and try to make out the tissues as shown in Fig. 44, 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 outgrowth 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.

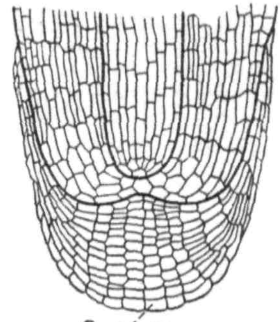


Fig. 44.—The Root-tip, in Longitudinal Section, magnified.

Exp. 9.—Cut transverse and longitudinal sections of the main root of Broad Bean or Scarlet Runner seedlings, stain with aniline chloride, and examine with the microscope (Fig. 43). Note the yellow-stained wood-bundles (usually five in Broad Bean and four in Runner); the phloem-bundles alternating with the wood-bundles are not so easy to recognise clearly. The wood contains vessels and the phloem contains sieve-tubes, as in the stem-bundles. The vascular cylinder is surrounded by a sheath, and outside of this is the cortex whose cells often store food besides conducting water from the root-hairs to the vessels in the wood-bundles.

The sheath around the vascular cylinder is very important, since part of it gives rise to the rootlets, besides helping to produce the secondary thickening of the root and also (usually) producing the cork-forming layer (cork-cambium). Each rootlet arises as a swelling of the sheath just outside a wood-bundle; this explains the fact that the rootlets are arranged in definite longitudinal rows on the parent root (see Art. 45, *a*). As the young root grows it pushes its way to the surface and breaks out from the parent root.

97. Functions and Structure 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 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.

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. 45, 46).

It is important to realise that the bundles in the stem are continuous with the veins of the leaves on the one hand and with the veins in the vascular cylinder of the root on the other.

Exp. 1.—Place whole plants, or seedlings, or cut shoots of different plants, into water coloured with red ink, set them where the conditions are favourable for transpiration, and after an hour or so cut across the stem a few inches above the level of the coloured water. If the latter 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.

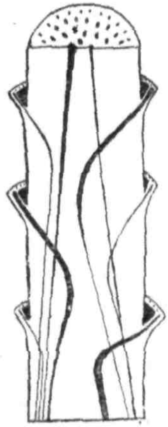


Fig. 45.—LONGITUDINAL COURSE OF THE BUNDLES IN A MONOCOTYLEDONOUS STEM.

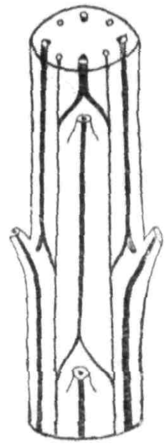


Fig. 46.—COURSE OF THE BUNDLES IN STEM OF A DICOTYLEDON.

EXP. 2.—Make thin cross-sections and longitudinal sections of these stems. In most cases the bundles are arranged in a single ring; this arrangement is found in most Dicotyledons. In the stems of Monocotyledons the red-stained bundles will be seen to be scattered through the stem (see Exp. 10, below). Notice that in most cases only the inner part of each bundle is stained. In Vegetable Marrow and Cucumber the bundles are in a double ring, and here the central part of each bundle is stained (see Exp. 9, below).

Exp. 3.—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.

Exp. 4.—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.

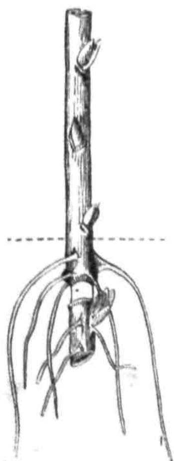


Fig. 47.—A Ringed Branch of a Willow sprouting in Water.

Exp. 5.—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. 47). 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 organic food passes down chiefly through the soft outer region of the stem.

Exp. 6.—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.

Exp. 7.—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.

Exp. 8.—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 and aniline chloride solution; the former makes the soft tissue transparent, the latter stains the hard woody tissue yellow.

Exp. 9.—The Vegetable Marrow (or the Cucumber) is one of the most suitable plants in which to study the tissues of the stem (Fig. 48). Cut across the stem, and note (1) the central cavity; (2) the (usually) five ridges, and furrows alternating with these; (3) the bundles (usually ten) arranged in two rings.

Scrape gently the outer surface of the stem, and remove part of the epidermis or skin, which is thin and colourless and bears hairs. Notice the soft tissue which lies between the bundles; this is the ground tissue, 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 sheath of hard tissue. Slit a piece of stem by two longitudinal cuts, and by scraping isolate a strip of this hard tissue. 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. Treat this fibrous tissue with aniline chloride solution: it turns yellow, being woody like the vessels in the wood of the vascular bundles.

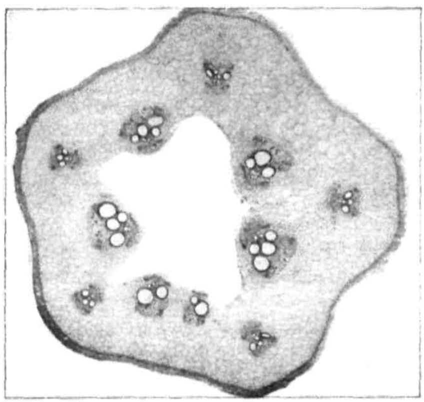


Fig. 48.—Transverse Section of Stem of Vegetable Marrow.

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.

Next cut across a piece of fresh Marrow 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 phloem,[1] and they also consist chiefly of tubes; but the phloem-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 phloem-tubes is thicker than water; collect some of it, place it on a glass slide, and test it for starch and for proteins by adding a drop of iodine solution.

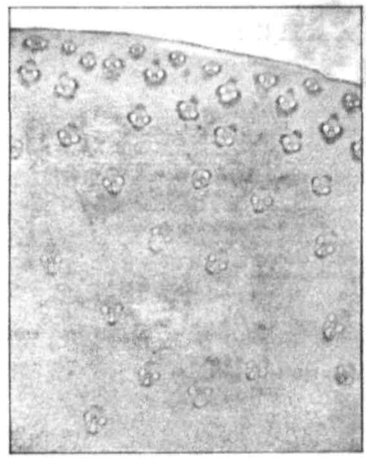


FIG. 49.—PART OF A TRANSVERSE SECTION OF STEM OF MAIZE.

EXP. 10.—For comparison with the stems of Dicotyledons, cut transverse sections of the stem of Maize (or of some other Monocotyledon, as the flowering stem of Lily, Narcissus, etc.), and note that the bundles are "scattered" all over the section—that is, they run down the stem at different distances inwards—but are more crowded towards the outside (Fig. 49). In Maize each bundle has around it a sheath of fibrous tissue which, like the vessels in the wood of the bundle (easily seen with a lens), is stained yellow by aniline chloride solution. The phloem in each bundle is immediately outside the two conspicuous large vessels.

[1] The Marrow, Cucumber, and some other plants are exceptional in having phloem on the inner side of the wood as well as on the outer side. In most stems the phloem occurs only on the outer side of the wood. The phloem-tubes are called *sieve-tubes*, because they are interrupted by cross-walls which are perforated like a sieve (*sieve-plates*).

98. Secondary Thickening of Stem.—In the stems of Monocotyledons the bundles remain separate from each other, but in Dicotyledons the older parts of the stem show a continuous ring of wood as seen in cross-section—*i.e.* a continuous zone or tube of wood. The joining up of the originally separate bundles and the formation of this continuous zone are due to the activity of a layer of growing and dividing cells (*cambium*) which lies between the wood and the phloem and which gives rise to new wood on its inner side and new phloem on its outer side (Fig. 50).

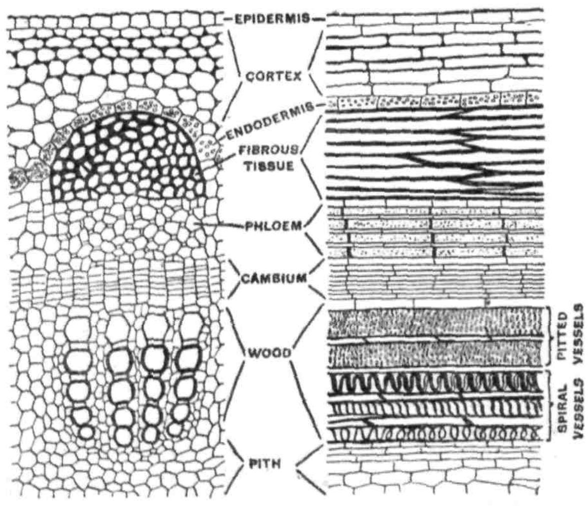


Fig. 50.

Partly diagrammatic transverse (left) and longitudinal (right) sections through a young Dicotyledonous stem, showing the various tissues.

The cambium can only be seen with the microscope, but the results of its activity are easily seen in stout herbaceous stems such as the Sunflower. If we cut transverse sections from successively older parts of a Sunflower stem, starting at the top, and treat them with aniline chloride solution, we find that the originally separate bundles become joined up by the formation of a continuous zone of wood which gradually becomes thicker in passing to older parts of the stem. If we cut a similar series of sections from the twig of a shrub or a tree we find that the same change takes place, but it goes much farther. In a twig which shows the "girdle-scars" (Art. 125) clearly we find that below the first girdle the wood shows two layers, below the second girdle three layers, and so on. These are the *annual rings* of wood, a ring being formed each year. On examining a thin section with a microscope (Fig. 51), or even with a lens, we see that the outer part of each ring of wood is compact, while the inner part of the next ring contains wide vessels; it is owing to this abrupt change from the compact autumn wood to next year's open-textured spring wood that the appearance of rings is due. The "rings" are of course concentric *layers* of wood, as is seen on making longitudinal sections. The wood formed in autumn is close-grained because at this time of year less water is carried up the stem (the leaves are becoming less active); in winter no more new wood is formed; then in spring the opening buds and expanding leaves require a large supply of water, and large vessels are formed to carry this upwards.

In transverse sections of woody twigs we notice a number of lines running radially through the wood: these are the *rays*. If we treat with iodine solution a section of Oak stem showing a few annual wood rings, we note that the rays (also the tissue outside the wood) are stained deeply, showing that the rays contain starch. One of the functions of the rays is to store food; they also serve to bind together the concentric layers of wood, and to carry water in a radial direction from one part of the wood to another.

The *knots* which occur so commonly in wood are the bases of branches which have become surrounded by the new layers of wood produced as the stem grew in thickness. When branches die away, or break off, their stumps are covered by a healing tissue (cambium) which forms new wood over the stump, so that it becomes buried in the wood; hence some knots only run for a short distance in the wood, and the reason why knots are so much harder than the rest of the wood, and easily fall out from thin slices, is that they have become compressed by the force of the growing wood around them.

The younger parts of a shrub or tree twig are green, like a her-

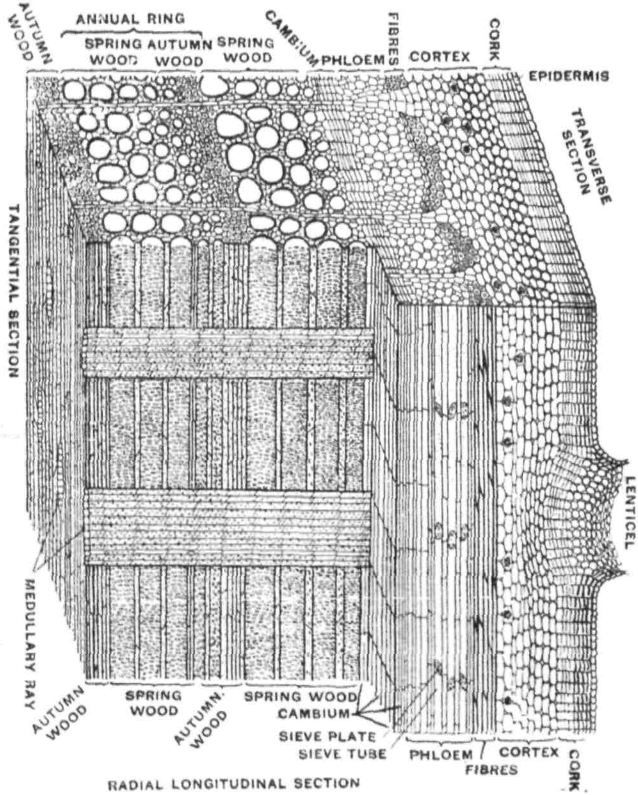


Fig. 51.

Outer portion of a woody Dicotyledonous stem, showing the structure of the tissues in a partly diagrammatic manner. The upper portion of the diagram shows the tissues in transverse section; on the left the wood is shown in tangential longitudinal section; in the middle the wood is shown in radial longitudinal section, then (towards the right) the cambium is cut tangentially, and finally the outer tissues (from cambium to epidermis) are again cut radially. The transverse section shows two medullary rays traversing the phloem, cambium, and wood; two annual rings of wood are shown; two medullary rays are seen traversing the wood in the radial section, and several rays are cut across in the tangential section on the left; some cluster-crystals of oxalate of lime are shown in the cortex cells; a lenticel is shown on the right of the diagram.

baceous stem, chlorophyll being present in the tissue (cortex) just below the colourless epidermis, but in older parts the surface becomes brown owing to the formation of *cork*; if we peel or scrape off this cork we find the green tissue is still there. The cork is an impermeable tissue developed to replace the epidermis, and it is produced as a rule by the cells just below the epidermis becoming active and forming a growing layer or cambium (cork-cambium). *Bark* is the name given to the dead tissue lying outside a cork-cambium.

The first cork-cambium formed may persist for a large number of years, or even throughout the life of the tree; in such cases 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, and 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.

In some trees the bark comes away in *sheets*; 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*; 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.

In the cork layer there are a number of raised patches, called *lenticels* (see Fig. 51), usually oval in outline, but transversely elongated and very conspicuous by their dark colour on the white cork in the Birch. If we strip the cork from twigs of Elder and other trees which show lenticels plainly, we see that the lenticels are not merely surface marks, but pass right through the cork to the cortex below. The lenticels are simply places where, instead of forming a compact impermeable tissue, the cork develops as loose cells, forming a powdery mass through which gases can pass into and out of the living tissue below. Just as the cork replaces the epidermis in function, so the lenticels replace the stomata of the young stem.

CHAPTER X.

GROWTH, MOVEMENT, ADAPTATION.

99. Measurement of Rate of Growth.—Seedlings of Broad Bean, Pea, and Phaseolus (French Bean or Scarlet Runner) afford excellent material for experiments on the rate of growth in length of roots and stems. The Broad Bean and Pea seeds should in most cases be placed with the hilum downwards; the Phaseolus seeds should be laid horizontally so that the root will grow out at right angles to the long axis of the seed.

The rate of growth of a growing organ (root, stem, leaf, etc.) is not uniform, and the same applies to each of its constituent cells. A growing structure, even under constant external conditions, does not undergo equal amounts of growth in equal successive time intervals. When growth begins, its rate is at first slow; then it gradually becomes accelerated until a maximum rapidity is reached, after which it gradually diminishes until growth ceases altogether. This rise and fall in the growth rate, extending over the whole of a growth period, is called the "grand period of growth."

Exp. 1.—Grow Phaseolus seedlings in pots of soil, and make daily measurements of the epicotyl (the stem region between the cotyledons and the paired primary foliage-leaves); as long as the tip of the epicotyl remains curved, measure with a strip of paper.

Exp. 2.—Also measure separately the daily growth in length of the successive internodes of a Bean or Pea seedling, and note that (1) each internode grows at first slowly, then its daily increase in length becomes greater, and finally falls off again until it stops; (2) when the internodes have fully elongated the oldest are usually relatively short, then come longer ones, while the youngest internodes are again shorter.

100. Distribution of Growth in Growing Organs.—The preceding experiment suggests a simple method for finding out whether or not any portion of a growing organ elongates uniformly, *i.e.* for investigating the *distribution* of rate of growth in length of roots and stems. All we have to do is to mark the organ with parallel transverse lines at regular short intervals; waterproof Indian ink may be used, and applied carefully with a pen or fine brush.

EXP. 1.—When the root of a Bean or Pea seedling has grown about 5 cm. long dry its surface if necessary by stroking it with torn bits of blotting or filter paper, and mark it with transverse lines 2 mm. (or, better, 1 mm.) apart, starting from the tip of the root.

Pin the seedling to the underside of the cork of a wide-mouthed jar with a little water at the bottom, or to a piece of wood placed over the mouth of the jar, so that the seedling may grow in moist air; or place it in the bulb of a long thistle-tube, the seedling being packed in with wet moss or cotton while the root grows down the tube, which is set in a jar containing water.

Examine daily, and note that the marks just behind the tip of the root become widely separated, while those farther back change little or not at all.

EXP. 2.—Mark the epicotyl of a Phaseolus seedling in the same way, starting at the point where the two primary foliage-leaves are borne and working down towards the cotyledons. The marking may be done when the epicotyl is 5 cm. or even more in length, because in stems the zone to which growth is limited is much longer (3 or 4 cm. in Phaseolus epicotyl) than in roots (4 to 8 mm. as a rule). Hence in dealing with stems and flower-stalks it is sufficient to make the marks 5 mm. apart.

101. How Light influences the Direction of Growth.—All are familiar with the turning of shoots towards the light, as shown by plants growing near a window. The growth curvature which plants make in response to light is called *phototropism* or *heliotropism*. Ordinary erect shoots grow towards the source of light, the stem tending to place its axis parallel with the direction of the light (*positive phototropism*), while the leaves place their surfaces at right angles to it (*diaphototropism*). Most roots and some stems grow away from the light (*negative phototropism*).

EXP.—Grow seedlings of Bean, Wheat, Sunflower, etc., in darkness: the shoots are erect. Now place them in front of a window, or in some other position where the light falls on them mainly from one side, and note the changed direction of growth of the shoots. When marked curvature has taken place, turn the seedlings round again, through 180°, and note the result.

102. How Gravity affects the Direction of Growth.—We have seen that in whatever position a seed may be placed the radicle grows vertically downwards into the soil, while the shoot grows vertically upwards into the air. In both cases the growth takes place against resistance, and is a response to the stimulus of *gravity* (gravitation); the radicle is *positively geotropic*, the plumule *negatively geotropic*. In both cases the organ can be induced to grow out of its normal vertical direction on being exposed to the influence of light coming from one side, and we shall see presently that moisture also can cause the root to deviate from the vertical direction. If we let a seedling grow for a time, till its root and shoot have reached a length of a few inches, and then take it up and lay it horizontally, the tip of the root will soon curve and grow vertically downwards, while the shoot will curve and grow upwards.

The secondary roots, or first order of rootlets given off by the radicle, grow away from the main root in a more or less horizontal direction—making a definite angle with the main root below the horizontal, *i.e.* sloping downwards. If we mark lines on the glass front of a box, to show the positions of the main root and its rootlets, and then tilt the box up so that it is supported at an angle of 45°, we find that the secondary roots as well as the main root curve until the former again take up the same angle as before with reference to the now vertically growing main root. The rootlets borne by the secondary roots do not respond to gravitation, but simply grow out at right angles to the roots which bear them, and the same is the case with the further branchings of the root-system. As in the case of phototropic curvature, we find that the region which curves in response to gravity is the elongating region.

The secondary roots are said to be *diageotropic*, taking up a definite more or less horizontal position in response to the gravitation stimulus. Diageotropism is also seen in branches of the stem, and in leaves, also in flowers which place themselves in a more or less horizontal position.

EXP. 1.—Grow Bean seedlings in a glass-sided box. When the root has produced a number of side roots, mark on the glass the positions of a few of these, also of the main root. Then tilt the box up at an angle of 45° and fix it in this position, setting it in darkness. From day to day note the change in the direction of growth of (1) the main root, (2) the side roots, (3) the shoot.

Various other simple methods may be used to demonstrate the fundamental facts of geotropism, using seedlings. For apparatus all that is needed is a receptacle in which the seedlings are given a supply of water, saturated air, and aeration daily; the apparatus should be set in the dark, to eliminate the influence of light on the direction of growth.

EXP. 2.—For small seeds, *e.g.* Wheat, place between two sheets of glass a sheet of wet blotting-paper; put the seeds between paper and glass, in different positions; put additional bits of paper at the corners to prevent too great pressure on the seeds, and clamp the glasses and papers together with clips. When the seedlings have grown, tilt the apparatus up at different angles, and note the directions of growth of the roots.

EXP. 3.—Pin Bean seedlings, with root horizontal, to the underside of the cork of a glass jar containing some water; or pin them to the upper side of a cork, set in a saucer of water, covering all with a bell-glass.

EXP. 4.—Take some Bean seedlings with roots about 5 cm. long, and mark the root of each with transverse Indian-ink lines 2 mm. apart, starting from the tip. Place the seedlings horizontally in a moist chamber or glass-sided box, and after a day or two measure the distances between the marks, the root having curved downwards. The region of greatest curvature corresponds to that of greatest growth in length; the curvature first becomes evident in the second zone from the tip, appearing later in the zones farther back, and the most active curvature is usually in the third zone.

EXP. 5.—The apogeotropic (negatively geotropic) curvature of the shoot will have been noticed in the preceding experiments, as contrasted with the positively geotropic curvature of the radicle of seedlings. It may be demonstrated in various ways. (1) Lay a pot of seedlings, or a potted plant, on its side; or invert the pot, after securing the soil from falling out. (2) Fix a cut shoot in the split or bored cork of a bottle or test-tube filled with water and laid horizontally. (3) Fix a shoot into a sloping bank of wet sand in a box; one end of the box may be replaced by a glass sheet, so that the changes in position of the shoot may be readily traced on the glass.

EXP. 6.—Mark the epicotyl of a Bean seedling, or the hypocotyl of a Sunflower or Castor Oil seedling, at intervals of 10 mm., starting from the tip. After twelve hours of horizontality, note the form of the curved stem, and measure the distances between the marks. The strongest curvature takes place in the region of greatest growth. Later, however, when the stem has become erect, the greatest curvature is at the base of the growing region, and it continues until the upper part of the stem is carried beyond the vertical, to which it returns at a still later stage.

EXP. 7.—Take four specimens of a single-flowered Narcissus in which the perianth tube is horizontal and at right angles to the flowering stem. Cut off each flowering stem a few inches below the flower, and stick it through the bored cork of a test-tube filled with water. Fix the four tubes so that the perianth-tube of *A* faces vertically downwards, that of *B* at 45° above the horizon, that of *C* 45° below the horizon, that of *D* vertically upwards. In which of the four does the flower-stalk curve so as to bring the perianth-tube into the horizontal position?

103. Growth of Twining Stems.—In a growing stem the tip does not simply grow straight upwards in a vertical line, even when the plant is placed in darkness so as to eliminate phototropic curvature; the growing tip sways to and fro as it grows upwards, thus describing a zigzag path, or it swings round in an ellipse or circle, thus taking a spiral path. This is easily observed if we fix a horizontal sheet of glass above a growing shoot and mark a dot of ink on the glass to indicate the position of the stem-tip as seen from above; after a time the tip will be seen to have moved away from its previous position. The "nodding" or nutation movements of the stem-tip are well seen in twining plants like Scarlet Runner, Hop, Convolvulus, etc., and we may conveniently use Scarlet Runner seedlings for experiments on the revolving movement of the stem-tip.

Experiments with Scarlet Runner.—Sow Runner seeds in pots of garden soil; as the seedlings grow up, leave only the strongest one in each pot. Note that the first few internodes of

Fig. 52.—TWINING PLANTS: I., CONVOLVULUS; II., HOP.

the stem grow erect and firm, but the later ones begin to bend so that the tip of the shoot nods to one side and becomes horizontal or even directed a little downwards. Get ready several vigorously growing plants.

EXP. 1. *Revolving Movement of Stem-tip.*—Take a plant in which the upper part of the shoot hangs over for 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.

This may be done in several ways: (1) by drawing lines on the paper radiating from the centre of the pot, so as to show the direction in which the stem-tip points; (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; (3) by fixing a sheet of glass above the plant and marking on it the position of the stem-tip. Whichever plan 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 clock[1] or in the opposite direction?

EXP. 2. *Influence of Temperature on Rate of Revolution.*—Compare the times taken by the same plant to make a complete revolution when kept first in a warm place and then in a cold place, or *vice versa*. At 33° C. a Runner plant revolved in 2 hours 20 minutes, while at 24° C. the plant took 3 hours 25 minutes to revolve.

EXP. 3. *Revolution causes Twisting of Stem.*—Mark an ink line along the convex side of the stem, and watch what happens during a revolution; place the plant as in the preceding experiment. If the shoot-tip faces north to begin with, at quarter revolution it will face west and the ink line will be on the left side of the stem; therefore the zone of most active growth (indicated by the convex side) has shifted 90° to the right, while the stem-tip has described a horizontal arc of 90° to the left. At half revolution the line will be on the concave side of the

[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 (Fig. 52, II.) 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.

stem, and so on until, when the revolution is complete, it regains its original position, and has then described a spiral.

Exp. 4. *Inclined and Horizontal Supports.*—Try the effect of setting the stick in an inclined position, in one pot at 30° from the vertical, in another at 45°, in another at 30° above the horizontal, and lay a fourth pot plant horizontally. Note that the Runner, like most other twiners, cannot climb up a stick set at more than 45° from the vertical.

104. Movements due to Contact.—Various organs of plants show very marked movements due to the stimulus of *contact* or *friction* with solid bodies. If a root in its growth through the soil comes in contact with a stone it grows along the surface of the stone and on reaching its edge resumes its former direction of growth; that roots are sensitive to contact and grow away from the obstacle is easily proved on attaching to one side of a root, near the tip, a solid body such as a piece of cardboard—the root-tip curves towards the side away from the object.

Movements in response to contact or friction are well shown by *tendrils*, the coiling of which around supports is an entirely different thing from the growth of a twining stem, though of course the object aimed at and the result obtained are the same in both cases.

Experiments with Tendrils.—Some simple general experiments may be made with the tendrils of Garden or Sweet Pea plants raised in pots or boxes.

Exp. 1.—Note that (1) the young tendrils are slightly hooked at the tip; (2) coiling results on stroking with a pencil or stick the more sensitive apical region of the tendril; (3) coiling is caused by a small loop of thread attached to the tendril-tip; (4) the tendrils will coil around supports placed at any angle whatever; (5) the sticks or other supports used must not be very thick, since the tendrils cannot coil around a thick support.

But since Pea tendrils make somewhat slow responses to stimuli, obtain if possible plants of Sicyos angulatus, Cyclanthera explodens, or Echinocystis lobata—all belonging to the Cucurbitaceae and easily raised from seed; other members of the same family are White Bryony—which answers fairly well—and (with much less sensitive tendrils) Cucumber and Marrow. In some species of Passion-flower the tendrils are sensitive enough for most experiments; those of Vine are much less so.

Exp. 2. *Growth of Tendril before Contact.*—In Sicyos, for instance, note that the tendrils as they develop from the bud are rolled up spirally; in a few days the tendril straightens out, performing meanwhile revolving movements; when these movements cease the tendril elongates rapidly, growth being greatest in the lower half of the tendril and amounting to about 50 per cent. or even more per day for three to five days; then for a few days the tendril grows slowly; then one-sided growth begins, the upper side growing more rapidly than the lower and thus causing the formation of a spiral. Carefully observe all these points; mark the tendrils with ink lines into zones and note the rate of growth daily.

Exp. 3. *Localisation of Responsiveness.*—Rub a tendril gently at different points with a thin stick, and note that it is *most irritable near the free end and on the lower side* (which is slightly concave in the young tendril ready to attach itself); if the upper side is rubbed, even in this terminal region, no curvature takes place.

Exp. 4. *The Response to Stimulation.*—Rub the inside of the terminal slightly hooked portion of a young tendril with a pencil or stick; the tendril soon shows a distinct curve, and forms a complete ring in a time varying according to the species and the external conditions—about six seconds in Cyclanthera, thirty seconds in Sicyos, one to two minutes in Bryonia. Stimulate the tendril more strongly —*e.g.* by drawing it between the fingers: it becomes rolled up more completely. After slight stimulation—just sufficient for the formation of a complete ring—the tendril soon begins to straighten again, though the undoing of the curvature takes considerably longer than its formation, *e.g.* about 25 to 30 minutes in Cyclanthera.

Exp. 5. *Changes in Tendril after Attachment.*—After the completion of the permanent coiling growth in length stops, and there appears not only in the coils but also in the rest of the tendril a number of changes.

A spiral twisting occurs in the basal region, whereby the stem is drawn closer to the support. This spiral changes its direction at least once, and that this reversal is due to purely mechanical causes may be demonstrated by fixing a strip of Dandelion stalk at both ends and placing it in water, or by trying to produce a spiral coiling in a piece of rubber tubing fixed at both ends.

As a rule, marked secondary thickening, accompanied by the development of fibrous tissue, appears not only in the part clasping the support, but also in the basal portion of the tendril. Compare transverse sections of (1) a tendril which has not yet clasped a support, (2) a tendril of the same plant after having made several coils round a support.

Exp. 6. *Tendrils with Sticky Pads.*—Observations should be made on the Self-clinging Virginian Creeper, which differs from most species of Ampelopsis (usually merged in Vitis, to which the Vine belongs) in that its branched tendrils become attached by means of sticky pads at the tips of the branches.

(1) Place a pot plant in a box with the open side facing the light: the leaves turn towards the light, while the tendrils turn away from the light towards the back of the box.

(2) Turn the plant round through 180°: the leaves and tendrils again curve as before—the tendrils show marked negative heliotropism.

(3) Set in the pot a flat strip of wood, close to the plant, and note that the tendrils spread out on coming in contact with the wood, the tips swelling to form sticky discs which adhere to the wood. For the first day or two the tendrils remain thin and weak, but later they become thicker and stronger, and some force is needed to tear them from the support. Moreover, they contract spirally after becoming attached, though before contact they do not revolve in the manner typical of tendrils.

105. Movements of Foliage and Floral Leaves.—In many plants the foliage-leaves and the flower-leaves perform movements generally described as "opening" and "closing" movements, or "sleep" movements, in response to various stimuli, such as contact or shock, changes from light to darkness and vice versa, changes in temperature. The general result of these movements is that the leaves are spread out to the air and light when conditions are favourable for photosynthesis and transpiration, and are brought into a more or less vertical position (so as to expose little surface to the sky) under conditions when a horizontal position would involve risk of injury through loss of heat by radiation or loss of water by transpiration. In the case of flowers or flower-heads the result of the closing movements is to protect the inner parts of the flower or head from these injurious influences.

In many plants the young growing leaves perform sleep movements, but these become less and less marked as the leaf grows older. In other cases the fully grown leaves retain the power of performing sleep movements, and these leaves are distinguished by having a pulvinus or motile organ.

In the movements of non-pulvinate leaves the day position is more or less horizontal and the night position vertical, the movements being due to curvature of either the petiole or the base of the blade. The leaves may sink at night, *e.g.* Balsam, Hop, Polygonum convolvulus, or they may rise and stand erect, *e.g.* Chenopodium, Polygonum aviculare, Stellaria, Linum, Mirabilis. In both cases the leaves pass in the evening from a horizontal to a vertical position. The cotyledons of some seedlings, *e.g.* Radish, spread out during the day and close up at night.

The movements of pulvinate leaves are of greater interest. In the leaves of various plants (especially Leguminosae and Oxalidaceae) movements occur which depend not upon growth but simply on unequal osmotic pressure on the opposite sides of the swollen leaf-base (pulvinus).

Experiments with Sensitive Plant (Mimosa pudica).—Specimens of this plant may be raised from seed, even with a cool greenhouse.

Exp. 1.—Note the alternately arranged compound (bipinnate) leaves, each leaf consisting of a main stalk, from the top of which diverge four secondary stalks, each bearing numerous leaflets in pairs. A pulvinus is found at the base of (i) the main or primary stalk, (ii) each of the secondary stalks, (iii) each of the leaflets.

At the large basal primary pulvinus the movements are in a vertical plane, raising or lowering the whole leaf; the movements of the four secondary pulvini cause the approximation or separation of the four secondary stalks; while the movements of the pulvini at the bases of the leaflets cause the latter to move upwards (so as to bring their upper surfaces in contact) or to spread out horizontally. The leaves of Mimosa perform movements as the result of (1) shock or contact, (2) changes of temperature and illumination.

EXP. 2. *Day and Night Positions* (Fig. 53).—Note that during the day the main stalk is directed upwards, making with the stem an angle of about 60°; the secondary stalks diverge, the two lower standing at right angles to the main stalk, the two upper forming an angle of about 60° with each other; and the leaflets spread out horizontally, forming angles of about 90° with the secondary stalks in the same plane. At night the primary stalk bends downwards through about 90°; the four secondary stalks bend forwards, so as to place themselves almost parallel with the axis of the main stalk; the leaflets bend upwards, coming together in pairs with their upper faces and also twisting slightly so as to form an acute angle forwards with the secondary stalk, the lower leaflets overlapping the upper ones like tiles on a roof.

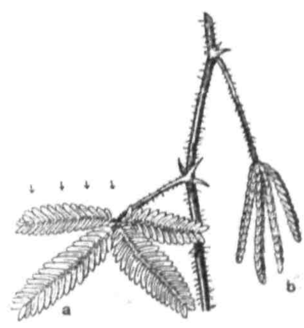


Fig. 53.—LEAVES OF MIMOSA PUDICA (THE SENSITIVE PLANT).
a, Expanded day position; b, Drooping folded night position.

EXP. 3. *Effects of General Mechanical Stimulation.*—Shake a Mimosa plant: the leaves rapidly assume the "night" position. After a short time they regain the normal "day" position; in fact, as soon as the main stalk reaches the position of maximum depression, it begins to rise again, and in 10 to 15 minutes the original position is regained. Shake the plant continuously for several minutes: the leaves become insensible to shock, and resume their normal position while the shaking is continued, but in 5 to 15 minutes after the shaking has stopped the leaves become sensitive again.

EXP. 4. *Sensitiveness of Lower Side of Pulvinus.*—With a pencil or thin stick tap or rub the upper surface of the large pulvinus at the base of the petiole: at first there is no response, even to vigorous stimulation, but if it is continued a response is eventually obtained. Now gently tap or rub the lower side of the pulvinus: an immediate response is made to even a slight stimulus.

EXP. 5. *Effect of Repeated Stimuli.*—With a light piece of wood strike the lower side of the main pulvinus repeatedly, at intervals of half a minute for about 5 minutes. On leaving the plant to itself the leaf rises, but at first it does not respond at a stimulus, though it soon regains its irritability. If the blows are applied more frequently—about ten per minute—the stalk falls at first but afterwards rises (in spite of the continued blows), and is then insensible even to stronger stimuli for some time.

EXP. 6. *Heat as a Stimulus.*—Hold a lighted match below the tip of one of the four secondary stalks and note the successive closing of the leaflets of this stalk; then the stimulus travels in the opposite direction from the bases of the other three secondary stalks towards their tips; finally the main stalk sinks, and if the stimulus is continued the neighbouring leaves are also affected.

Experiments on other Plants showing "Sleep" Movements.—Examine the leaves of Phaseolus (French Bean, Scarlet Runner), Clover, and Wood Sorrel. Note that in Phaseolus a pulvinus is present not only at the base of the petiole, but also at the base of each leaflet. Study the day and night positions of the leaves of these plants, as well as of others showing sleep movements, *e.g.* False Acacia (Robinia).

In Clover leaves note that by day the three leaflets are spread out horizontally from the top of the stalk; at night the two basal leaflets rotate until they stand in the vertical plane, then they swing round till their upper surfaces come together, and finally the end leaflet rotates upwards through 180° and comes down like a roof over the edges of the other two leaflets.

Exp. 1.—On a bright day cover with a flower-pot or dark box a Clover plant growing in the open, or one dug up and set in moist soil in a saucer: note that in about half an hour the leaves have assumed a night position.

Exp. 2.—Keep a Clover plant in darkness for a week, and note that the leaves ultimately assume a position resembling the day position, except that the leaflets are more drooping.

In Wood Sorrel note that by day the three leaflets spread out horizontally, as in Clover; at night they droop so that their midribs touch the leaf-stalk, while each leaflet becomes folded along the middle. Repeat the experiments given for Clover.

Experiments on Temperature Effects in Tulip and Crocus Flowers.—Use pot plants, or cut flowers set in bottles of water.

Exp.—In the morning bring a closed flower from outside, or from a cold place indoors at about 10° or 12° C., into a warm room at about 20° C., and note that the flower soon begins to open. Keep some Tulip plants at 12° C. from 5 p.m. until about noon next day, and then transfer to 18° C.: during the first hour the flowers open, but during the second they close again.

Experiments on Opening and Closing of Composite Flower-heads.—Various Compositae may be used for experiments on the opening and closing movements of floral leaves.

Exp.—Cut off a Daisy or a Dandelion with the flower-head open, fix it in a bottle of water, and place it in darkness. Note the time required for a distinct closing movement;

this may be done by marking two opposite ray-flowers with a spot of ink and measuring the horizontal distance between the tips of these flowers before and after placing the plant in darkness.

The flower-heads of Daisy and Dandelion are sensitive to temperature as well as to light, but their responses to temperature are feeble as compared with those made by Tulip and Crocus flowers. If closed Daisy heads are brought indoors at night they do not open, though the rise in temperature may be as much as 15° C.; nor does a corresponding fall in temperature make the open head close during the day. But if in the morning the closed heads are warmed through 15° they will open, and if at evening the open heads are cooled through 15° they will close.

106. Adaptations of Climbing Plants and Water Plants. —We have already considered in a general way (Art. 43) the fact that plants are adapted in various ways for different modes of life. As examples of such adaptations we may take climbing plants as illustrating the fact that very different parts of a plant may be modified so as to serve a particular function, and water plants as illustrating the fact that plants belonging to quite different families may come to resemble each other more or less closely (so far as their vegetative organs are concerned) because they are adapted for life in the same environment.

Climbing Plants.—We have studied in some detail the movements shown by twining stems and by tendrils, but there are various other methods of climbing. The biological advantages of the climbing habit are fairly obvious. Instead of slowly building up a stiff stem, strengthened to resist the action of wind and to hold out the leaves and flowers to the air and light, the climbing plant attains these objects at a comparatively slight expense of material and energy by attaching itself to other plants or other supports.

A simple method of climbing is shown by the Stitchwort, the star-like white flowers of which are seen in almost every hedgerow in spring. The plant bears long narrow leaves in opposite pairs, and at first the leaves are close to the stem, so that the growing shoot can insinuate itself among the branches of other plants, then the leaves spread out horizontally and support the plant. Another simple method of climbing, or, rather, scrambling, is seen in Roses and Brambles, the prickles of which are often curved backwards so as to catch hold of any support. The Goosegrass, also common in hedgerows, grows at first erect, like Stitchwort, but soon the shoots come into contact with supports and the small recurved prickly hairs which cover the stem enable the plant to catch on to the support, and if we disentangle the Goosegrass from the hedge we see that the long shoots are quite limp and unable to support themselves.

In Ivy climbing is effected by means of the short roots which grow out from the stem and insert themselves into any crevice on a rock, wall, or tree trunk. These roots grow usually on the shaded and moister side of the stem and are negatively phototropic, though in a shaded moist wood we often find Ivy with roots growing from all round the stems, not only from the side nearest the tree on which the Ivy is climbing.

Twining stems have been dealt with in some detail (Art. 103), and it is hardly necessary to emphasise further the sharp distinction between these twiners and plants which climb by means of the special irritable coiling organs called tendrils (Art. 104). It is interesting to note that tendrils may be formed from almost any part of the plant.

There are no British plants with root-tendrils, but in many tropical Orchids the plant produces, besides other forms of root, special root tendrils which coil around supports. In other cases the tendrils are modified branches (Passion-flower, Vine, Virginian Creeper, White Bryony); in others, modified leaflets (Peas, Vetches); in others the petiole (leaf-stalk) acts as a tendril (Clematis, Nepenthes, climbing species of Solanum, etc.); in Gloriosa (Liliaceae) the leaf-tip is prolonged as a tendril; in Smilax the tendrils are apparently stipules, being in pairs at the base of each leaf. The Dodder, a parasitic plant, is peculiar in that the whole stem acts like a tendril, being sensitive to contact and coiling around the plant into which it sends its absorbing organs or suckers.

Water Plants.—Many of the adaptive characters of water plants are illustrated by the different forms of Water Crowfoot (Fig. 54) which grow in streams and ponds and are easily recognised by their flowers, which have the same structure as that of ordinary Buttercups but have white petals. The varieties 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. The submerged leaves have chloroplasts in their 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 stomata, nor does the stem contain many wood-vessels.

Fig. 54.—Part of a Water Crowfoot, showing a floating leaf and two submerged leaves.

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 divided, and bear stomata on their upper surface, which is covered with cuticle or wax so as to prevent wetting. These floating leaves have the same 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. The air spaces enable the plant to float upright, but they also convey air to the lower parts growing in deep water or in mud, where little or no oxygen is present for respiration.

In forms which grow in shallow streams or pools, in marshes and muddy places, all or most of the leaves are of the entire, rounded or lobed, "floating" type. 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.

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.

In order to understand the adaptations of water plants, or of other biological groups of plants growing in special habitats, we must consider the conditions under which the plants live. Submerged plants are subject to less extremes of temperature than land plants, since, owing to its high specific and latent heats, water takes longer to be heated and longer to cool than soil does (see Arts. 17, 18). The mechanical conditions under which submerged plants live have already been referred to.

As regards nutrition, water plants are well supplied 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 in air (see Arts. 30, 39, 41). On the other hand, the proportion of oxygen dissolved in water (it need hardly be pointed out that water plants do *not* get their oxygen for respiration by the splitting up of water) is much smaller than that present in the air. In the lower parts of a fixed water plant, or a marsh plant (*i.e.* a plant having its leaves mostly, or all, in the air, but its roots and shoot-bases in water or mud), there is a poor supply of oxygen. The water or mud at the bottom is poor in oxygen as compared with the surface water: still or sluggish water contains less oxygen than running water. The air spaces found in the leaves, leaf-stalks, stems, and roots of water plants serve to convey air to the badly aerated parts; in submerged plants they serve also for support, but their primary importance for aeration is shown by their large development in marsh plants.

Another point to remember is that water absorbs light to such an extent that submerged plants are growing under the same light conditions as shaded land plants. This seems to account partly at least for the long "internodes" of the stem, the absence of palisade tissue in the leaves, and some other features.

Since a water plant obtains its water, salts, and carbon dioxide so easily, and lives in very favourable conditions generally, it grows rapidly, branches freely, and reproduces itself largely by vegetative means, chiefly by the decay of the older parts setting the branches free, or by branches breaking off. The water plants of tropical regions grow continuously all the year round, not being hampered by either a cold or a dry season. In temperate regions growth is interrupted by the winter, and various methods of perennation occur (practically all water plants are perennial). In some cases—*e.g.* Callitriche—the plant remains unaltered, merely sinking to the bottom; in Water-lilies food is stored up in the rhizome; in Arrow-head tubers are formed. A very common mode of perennation is the formation of winter buds, which are developed at the ends of the branches. These buds are large, their leaves contain reserve food; they drop off and remain at the bottom during winter, growing up in the spring. Winter buds of this kind occur in Water Milfoil, Water Violet, Bladderwort, Frog-bit, and various species of Potamogeton (Pondweed).

What we may term "typical" water plants grow with the entire 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 such amphibious plants the leaves of the land form are broader, and the stem- and leaf-structures resemble those found in ordinary land plants.

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 to 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 East 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 Sweetgrass** (Glyceria fluitans); **Grass-wrack** (Zostera), on shores and especially in estuaries, with leaves 1 to 4 feet long; **Horned Pondweed** (Zannichellia), in fresh or brackish pools and ditches, with opposite leaves 1 to 3 inches long; and several species of **Pondweed** (Potamogeton). The **Canadian Waterweed** (Elodea, or Anacharis), in streams, has narrow pointed leaves about 2 cm. long, arranged in threes on the stems. **Water**

Starwort (Callitriche) grows very commonly in still waters and is erect, 3 to 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 **(Pondweeds)** we get species showing all transitions from broad floating leaves (*e.g.* P. natans, the commonest species) to long narrow submerged ones. In P. heterophyllus the upper leaves float but are narrower than in P. natans, and the lower ones are submerged, very narrow, and 2 to 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, stomata, 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.

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.

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 to 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** (Hottonia) and **Bladderwort** (Utricularia) are free-floating (not rooted) plants, entirely submerged (except the flowering stems).

CHAPTER XI.

GENERAL CHARACTERS OF VEGETATIVE ORGANS.

107. The Root System.—We have seen that the different directions taken by the main root and its successive branchings result in the thorough exploration of the soil by the root. The growing root-tips, with their root-hairs, come into contact with a large amount of soil, in order efficiently to perform the primary functions of the root in land plants—namely, to *fix* the plant in the soil and to *absorb* soil-water, which contains dissolved salts essential for nutrition and growth. When the radicle persists and forms the main root, from which all the other roots of the plant arise, the plant is said to have a *tap-root* system. A tap-root is found in most annual Dicotyledons, *e.g.* Shepherd's Purse, in those perennials which have ordinary erect stems (not creeping under or on the soil), and in most shrubs and trees. In many perennial herbaceous Dicotyledons and in nearly all Monocotyledons, however, the radicle soon dies off and roots are formed from the stem; such roots are called *adventitious.*

In many cases the roots, after being buried in the soil, contract and so draw the stem into the ground, the root becoming wrinkled as the result of the contraction. This occurs in many plants with a tap-root and a short stem with leaves crowded on it, *e.g.* Dandelion, Plantain; and it is well seen in Monocotyledons with bulbs and corms—the young bulb or corm produces one or more of these contractile roots, which serve to pull the bulb or corm downwards and at the same time away from the parent bulb or corm. The branches of Brambles often grow out into long trailers with small leaves; the tips of these branches produce roots on reaching the soil, and by the contraction of these roots the tip is fixed in the soil and may give rise to a new plant when the part behind the tip dies away.

Since practically all roots have the same functions—fixation and absorption—and grow under the same conditions, buried in

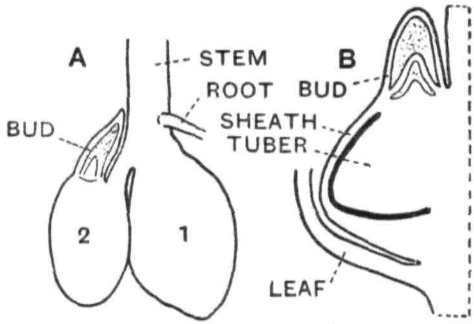


Fig. 55.—Early Purple Orchis.
A, Base of a Plant (dug up in summer), with old (1) and new (2) Tubers; B, Section of a developing Tuber.

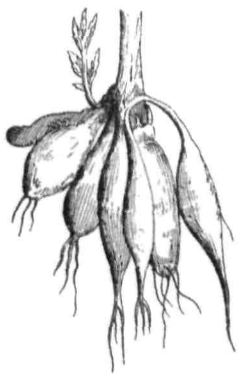


Fig. 56.—Tuberous Roots of the Dahlia.

the soil, the roots of different plants show great uniformity in form and structure. Some submerged water plants have no roots at all, *e.g.* Bladderwort, Water Violet (Hottonia); the Duckweeds, which float on the surface, have roots which dangle in the water and do not become fixed, but serve only for absorption; in most rooted water plants, especially those growing in streams, the roots probably serve only for fixation, not for absorption. In addition to, or instead of, their usual functions of fixation and absorption, the roots of land plants may take on other functions. By far the commonest of these is *food-storage*, either the tap-root, as in Carrot, Beet, etc., or adventitious roots, as in Lesser Celandine, Orchis (Fig. 55), Dahlia (Fig. 56), etc., becoming swollen owing to the quantity of stored food (starch, sugar, etc.). In some cases where the plant has a swollen root-like organ, closer inspection shows that this is really made up entirely or partly of the basal portion (hypocotyl) of the stem, as in Radish, Turnip, etc.

In Ivy the stem produces adventitious roots which serve for *climbing*, since they fix the stem to walls, rocks, or tree-trunks; it is wrong to call these roots tendrils, for they do not coil around the support. It is also wrong to call the Ivy a parasite, for the climbing roots do not penetrate the tree and take food from it. In some plants the roots do this, as in Mistletoe, where the root burrows into the tissue of the tree and takes at any rate water and salts from it; since the Mistletoe has green leaves, serving for photosynthesis, it is called a *partial parasite*. Other partial parasites are Cow-wheat, Yellow and Red Rattles, etc., the roots of which become fixed to the roots of other plants (chiefly Grasses).

Other plants are *total parasites*, e.g. Broomrape, Toothwort, the roots of which become fixed to those of other plants and take water, salts, and organic food materials from them; these total parasites have no green leaves, and obtain all their food from the "host" on which they grow. In Dodder the stem twines around those of other plants, the radicle dies away, and where the Dodder stem touches that of the "host" it sends in adventitious roots which act as suckers tapping the wood and phloem of the "host," so that Dodder is a total parasite.

In some cases the roots either contain, or are covered with, the threads of Fungi which are able to digest decaying organic matter in the soil and pass on the products to the plant. Such plants are called *saprophytes*, the Fungus threads with which the roots are associated enabling the root to obtain food other than the water and dissolved salts which ordinary roots absorb. This association between Flowering Plant and Fungus is called a *mycorhiza*, and it is a case of *symbiosis* or mutually beneficial partnership, the Fungus (especially when it penetrates the root) getting shelter, water, dissolved salts, and some organic food from the Flowering Plant, while in return it keeps the latter supplied with organic food obtained from the decaying organic matter in the soil. In some cases all the plant's food is obtained in this way—the plant is a *total saprophyte*, e.g. Bird's-nest Orchid. In other cases only part of the plant's food is obtained by means of the mycorhiza, the plant being a *partial saprophyte*; all forest trees and the majority of woodland plants in general have a mycorhiza in the form of a mantle of Fungus threads on their roots.

In the Pea family (Leguminosae) and a very few other plants the roots bear swellings (*tubercles* or *nodules*) inhabited by Bacteria which have the power of making nitrates from the free atmospheric nitrogen present in the soil air, to such an extent that these plants actually leave the soil richer in nitrates than they found it; this is another example of symbiosis, for the plant provides the Bacteria with shelter, water, salts, and organic substances like sugar, while the Bacteria provide the plant with a source of nitrogen which other plants are unable to make use of.

108. Types of Leaf.—A leaf is an organ carried on a stem and might therefore be called a branch of the stem, but it differs from an ordinary branch in several respects. A stem-branch, like a root-branch, simply repeats the structure of the parent organ and, like it, bears leaves and buds. A stem-branch arises in the axil of a leaf, hence when we find plants which have flat leaf-like branches we can easily tell that these are really branches. For instance, in the Butcher's Broom we find, in addition to ordinary branching of the stem, flat green leaf-like organs each of which arises in the axil of a scale and often bears a flower; here the true leaf has been reduced to a scale, while the branch has assumed a leaf-like form—green leaf-like branches like this are called *cladodes* or phylloclades, and they serve the same functions as true foliage-leaves.

Besides green *foliage-leaves* and reduced, usually colourless, *scale-leaves*, there are two other types of leaf—*cotyledons* or seed-leaves, and those leaves which are found connected with or forming part of the *flower*. The flower usually arises in the axil of a leaf called a *bract*, while the outer parts of the flower itself are also leaves (*perianth-leaves, sepals, petals*).

109. 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, 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 (some Thistles), while it may even unite around the stem so as to form a *perfoliate* leaf (Yellow Gentian). Occasionally the leaf-base becomes thick and fleshy, and forms an irritable organ or organ of movement known as the *pulvinus* (Art. 105).

110. Stipules.—Very commonly outgrowths arise from the base of the leaf. These outgrowths are known as **stipules,** and vary much in size, form, and colour. When they are dry, pale, and membranous they usually serve only to help in protecting the young leaves, and fall when the leaves unfold. In the False Acacia (Robinia) the stipules are metamorphosed into spines, and in Smilax they become tendrils. In some Peas they are large and green, and actually take the place and function of the foliage-leaves, which are modified into tendrils.

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 ensheaths 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*.

111. 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 mid-rib, but in the Garden Nasturtium and in the Pennywort the stalk is attached to the middle of the under-surface (*peltate* leaf). The petiole may be winged (Sweet Pea), and it is usually cylindrical or semi-cylindrical, being frequently flat or 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 mid-rib, although in other cases a number of veins of equal size enter the leaf from the petiole. In Garden Nasturtium and Clematis the petiole has the power of coiling around supports, and hence it acts as a *tendril*.

112. 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 leaves of nearly all Monocotyledons have all their principal veins running parallel through the entire length (*parallel venation*). The leaves of Dicotyledons have their principal veins branching off from the mid-rib on either side, while the smaller ones form a delicate network (*reticulate venation*); this is also found in some Monocotyledons, *e.g.* Arum, Black Bryony.

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.

113. Simple and Compound Leaves.—Some leaves are *simple*; that is, their flat part or blade (*lamina*) is not divided into distinct portions, though it may be more or less 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 a series of drawings should be made illustrating the more typical shapes.

In *compound* leaves the blade is divided into distinct parts called *leaflets*, which may be arranged in opposite pairs along the central stalk as in the Rose and the Pea, or may all radiate from one point of the stalk as in the 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; but all gradations exist between leaves of widely different shape. The following list includes the commonest shapes :—

(1) **Blade broadest near the base**—*e.g.* **cordate** (heart-shaped), **sagittate** (arrowhead-shaped), **reniform** (kidney-shaped), **ovate** (egg-shaped), **lanceolate** (lancehead-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.**

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 modifications of leaf margins, all of which should be drawn from nature.

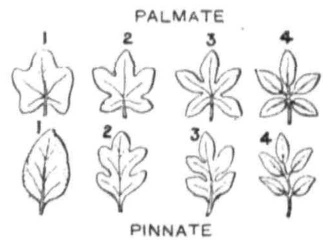


Fig. 57.—FORMATION OF PALMATE AND PINNATE COMPOUND LEAVES BY THE GRADUALLY INCREASING INCISION OF LAMINAS WITH PALMATE AND PINNATE VENATION RESPECTIVELY.

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 mid-rib, 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. 57), for the incisions will naturally fall between these.

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 mid-rib 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 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 stalk (petiole), whereas there are no buds in the axils of the leaflets.

114. 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.

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.* Labiates, 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 and in Heaths. The leaves are *apparently* in whorls in Goosegrass and Bedstraws, but closer inspection shows that only two of the apparent leaves in a whorl bear buds in their axils; the others are really stipules.

115. Leaf Mosaics.—A leaf which receives very little light 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 (Fig. 58), 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.

116. Decay and Fall of the Leaf.—Leaves are called *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

Fig. 58.—Leaf Mosaic illustrated in Horse Chestnut Foliage.

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.

117. 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 often called 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 shrubs and trees). In some plants the stems are more or less prostrate or trail along the ground. Many weak stems, however, which are unable to grow erect themselves, make their way upwards by attaching themselves to surrounding objects. These are known as **climbing** and **twining** plants.

In **climbing plants** the climbing is effected in various ways. The Ivy, for example, climbs by means of adventitious roots; these roots, developed on the stem, fix themselves to the trunk or wall on which the plant climbs. The Pea, the Passion-flower, the Vine, and many other plants climb by means of special organs called **tendrils.** These tendrils may be specialised stems, leaves, or parts of leaves. The Virginian Creeper climbs by means of adhesive, sucker-like discs developed at the tips of the branches of its tendrils; Clematis, by means of its leaf-stalks or petioles, which act the part of tendrils, and, in fact, are called *petiole-tendrils.* The Blackberry and Goose-grass (Cleavers) support themselves by means of hook-like prickles which enable them to scramble over other plants.

As distinguished from these, **twining plants** achieve the same result by themselves twining round some support, as, for example, the Hop, Convolvulus, Honeysuckle, and others.

118. Runner, Offset, Sucker, Bulbil.—Many plants give off special shoots, serving chiefly for purposes of vegetative production. Of these the runner, offset, and sucker are the commonest.

The **runner** (Fig. 59) is a slender shoot running along the surface of the ground, and often attaining a considerable length. It arises in the axil of a leaf, at the level of the soil. At intervals it produces small scale-leaves, with a bud in the axil of each. From the bases of these buds adventitious roots pass down into the soil, and in this way new plants are formed. Examples are seen in Strawberry, Creeping Buttercup, Sweet Violet, Silverweed, Daisy, etc.

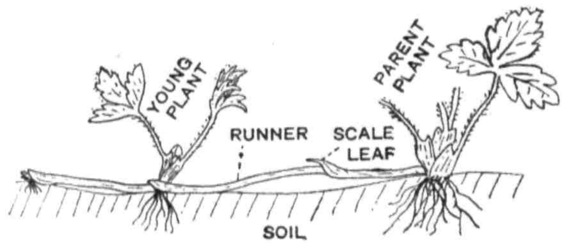


Fig. 59.—Runner of Strawberry.

The **offset** (*e.g.* in the Houseleek, Fig. 60) resembles the runner in origin, but is shorter and stouter. It is merely a short runner which turns up at the end to form a new plant.

Fig. 60.—Offset of House-leek.

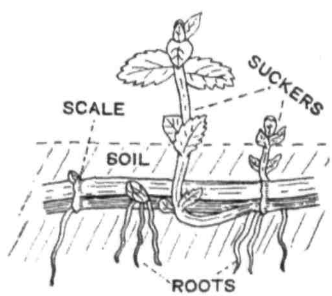


Fig. 61.—Suckers of Mint.

The **sucker** (Fig. 61) is an *underground* runner or branch; it grows upwards, develops roots and aerial shoots. These suckers are white or pink in colour and resemble roots, but are distinguished as stems by their axillary development and the possession of scale-leaves. Good examples are seen in Mint, Dead-nettle, and Raspberry.

Bulbils may be described as axillary buds, which become large and fleshy owing to the storage of food-material in their leaves. They differ also from ordinary buds in the fact that they separate from the parent plant, fall to the ground, and produce new plants, thus serving for reproduction (*e.g.* Lesser Celandine, some Lilies). They may also take the place of flowers (*e.g.* in the Onion, Garlic, some Grasses, etc.). In plants producing them seed-formation is usually uncertain.

119. 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 and buds, and by their origin from buds borne in the axils of leaves. The four chief types of underground shoots are Rhizomes, Tubers, Corms, and Bulbs.

The **rhizome** is a stem, often stout and swollen with reserve food, 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 grow out from the surface of the rhizome, usually near to the bases of scale-leaves—that is, from the "nodes." Rhizomes often branch, and each branch when separated by the decay of the older parts is capable of forming a new plant. The scars of leaves and branches are usually seen on the rhizome.

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.

Good examples are the rhizomes of various Grasses (*e.g.* Couch-grass) and Sedges, Iris, Solomon's Seal (Fig. 62), Wood Sorrel, Wood Anemone.

The **stem-tuber** is a swollen underground stem, or part of a stem, laden with food-material, and serving for purposes of vegetative reproduction, *e.g.* in the Potato and Jerusalem Artichoke.

In the Potato the tubers are borne on slender underground shoots, which are recognised as such not only by their internal structure, but also by the fact that they bear scale-leaves. The tubers make their appearance either at the apex of a shoot or in the axils of the scale-leaves, and instead of developing into normal branches become enormously dilated by the deposition

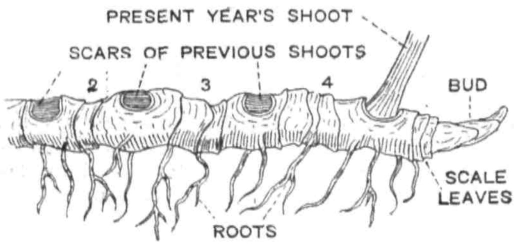


Fig. 62.—Rhizome of Solomon's Seal.

of starchy food-material. The tuber, however, is readily distinguished as a modified stem-structure, not only by its position of development, but also by the possession of buds, known as the "*eyes*." When a tuber, or part of a tuber, is placed in the soil under proper conditions, the buds or "eyes" develop at the expense of the stored food-material and produce new plants.

The **corm** (Figs. 63, 64, 65) 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 and most other corms), as in the upright type to which the name of "root-stock" is often applied. The swollen portion of the corm is packed with food-materials and bears brown scale-leaves, in the axils of which there are buds.

The buds develop in spring into erect flowering shoots at the expense of the stored food-materials, while adventitious roots arise from the base of the bud and also from that of the condensed stem. Later in the year, when flowering is over, the new supplies of food-material together with any remaining in the old corm, are stored up in the basal portion of the flowering shoot, which swells to form the new corm. The old corm shrivels up, and a bud arising from the new one forms the flowering shoot of the next year when winter is over, the life-history being repeated in this manner from year to year.

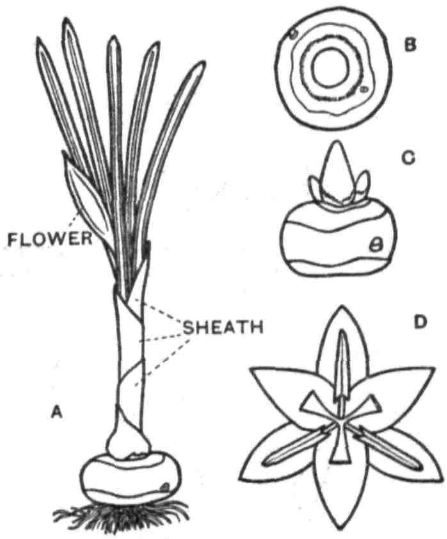


Fig. 63.—CROCUS.

A, Entire Plant just before the Flower has opened ; B, Corm from below ; C, Side view of Corm ; D, Flower as seen from above.

Additional buds may sometimes develop in the axils of the outer leaves, each producing a new corm, and these subsequently separate and form new plants; the same process occurs in bulbs.

Corms are found in Crocus (Fig. 63), Gladiolus (Fig. 64), "Autumn Crocus" or Meadow Saffron (Colchicum, Fig. 65), Arum, Bulbous Buttercup, Cyclamen, etc.

The **bulb** (Figs. 66, 67) may also be regarded as a short specialised underground shoot. It has a structure somewhat similar to the corm, but the stem or disc is comparatively small, and the food-material is stored up in the large, fleshy scales which

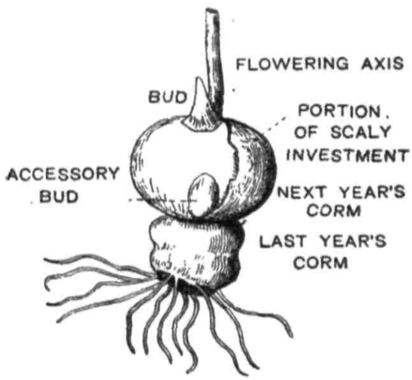


Fig. 64.—CORM OF GLADIOLUS AFTER REMOVAL OF ENVELOPING SCALES. The Bud forms the Corm of next year; the Accessory Bud separates and forms a new plant.

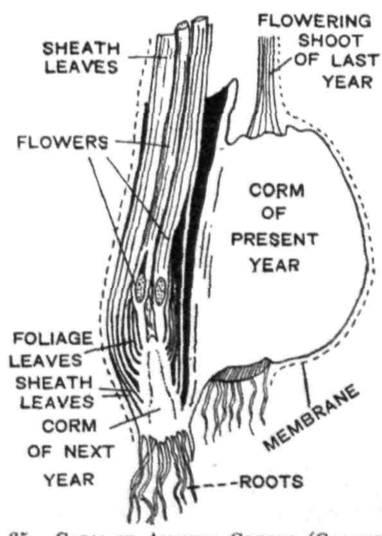


Fig. 65.—CORM OF AUTUMN CROCUS (COLCHICUM).
(Longitudinal section.)

invest and overlap the disc. These scales may be either scale-leaves, or the fleshy bases of foliage-leaves whose upper parts have withered. A bud is present in the axil of one of the innermost scales and in the spring develops at the expense of the stored food-material into a flowering axis surrounded by foliage-leaves, and also, it may be, by a number of scale-leaves. Adventitious roots are given off from the base of the bulb.

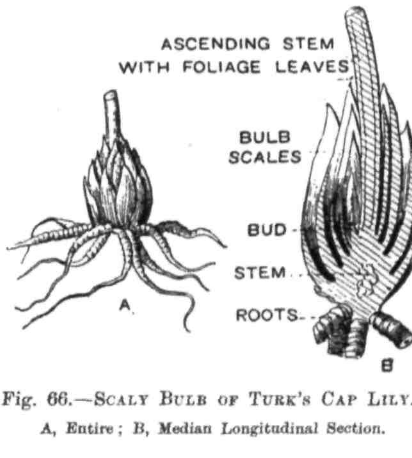


Fig. 66.—SCALY BULB OF TURK'S CAP LILY.

A, Entire; B, Median Longitudinal Section.

After flowering the food-material which is formed is stored up in the scale-leaves or in the bases of the foliage-leaves, and in this way a new bulb is produced, which will repeat the process the following year. Instead of a single bud, two or more may be present in the axils of the inner leaves. In this case the new bulbs formed from them separate from the parent bulb.

In **scaly bulbs** (*e.g.* Lilies, Fig. 66) the fleshy scales, of which the main bulk of the bulb is composed, simply overlap at their margins. In **tunicated bulbs** (*e.g.* Onion and Hyacinth, Fig. 67) the outer leaves are large and completely ensheath the inner portions of the bulb. The coloured membranous covering or tunic present on the outside of such bulbs is formed by the shrivelled remains of the leaves of a previous season.

120. 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, Gorse, etc., become modified into special protective

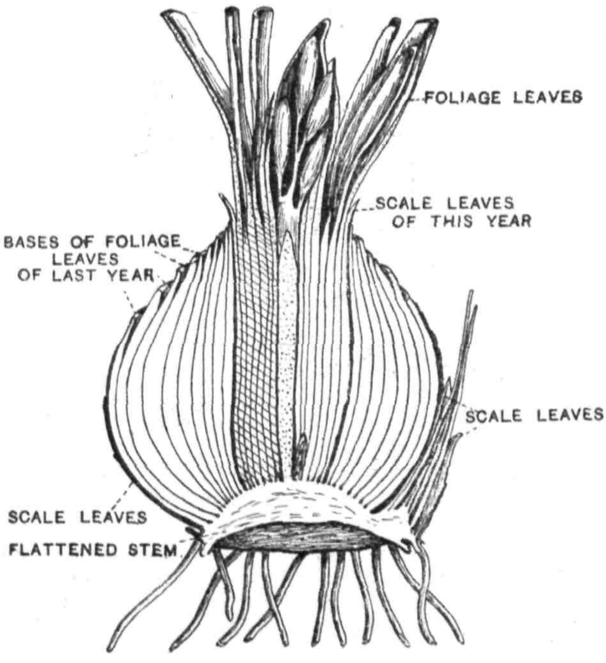


Fig. 67.—Vertical Section of Flowering Bulb of Hyacinth in Spring.

The shaded portion on the left marks this year's growth on that side. On the right the bud of next year is shown.

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. Such spines possess a central cylinder of vascular tissue, which is continuous with that of the stem, as can be seen when they are torn off.

Spines may also be developed from leaves. 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. 68) is often found to exhibit intermediate forms between leaves and spines. The foliage-leaves of the garden Acacia (Robinia) have a pair of spines which arise at the base of the leaf-stalk and are modified *stipules*.

Fig. 68. — BRANCH OF BARBERRY, SHOWING TRANSITION OF FOLIAGE-LEAVES INTO SPINES.

121. 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, leaving a tiny wound into which the acid juice contained in the hair is squirted by the contraction of the swollen base.

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 glutinous secretion. The leaves of a few plants, such as the Butterwort and the Sundew, have the power of partially digesting insects captured in this manner.

Prickles such as those of the Rose are usually classified as "emergences." This term is a convenient one for all irregularly situated outgrowths from stems or leaves, which are neither 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 shows 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 parts when growing in a poor, dry soil fully exposed to the rays of the sun becomes a much softer and less aggressive character when grown in a rich, moist soil. Under the former circumstances the plant not only protects itself from herbivorous animals, but also, 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 has no spines when grown in rich, moist soil, but in dry, exposed situations most of the branches end in hard, sharp points.

The hairs present on the stem and leaves are 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 excessive illumination, 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, are very permeable to water.

122. Buds.—From our study of seedlings we have seen that the shoot arises from the plumule or primary bud of the young plant in the seed. We have also seen that branches of the stem arise from buds (axillary buds) formed in the angle (*axil*) between the base of each leaf and the stem, while the free tip of the stem and of each branch is occupied by a terminal bud. A bud is simply a young shoot, consisting of an axis (stem) bearing young leaves which are closely crowded together.

The formation of a bud results from the fact that the end of the stem grows slowly as compared with the leaves which it has produced. At first each leaf grows more on its outer (lower) side, so that the older leaves bend over the tip of the stem and thus protect both the younger leaves and the growing-point of the stem. Hence the bud is at first closed up, but later it becomes loosened and opens out; the inner (upper) side of each leaf now grows more than the outer side for a time, hence the leaves become flat and at the same time spread out from the stem, besides growing larger. In most cases the opening of the bud is accompanied by growth in length of the stem, so that the points of insertion of the leaves become separated by bare parts of stem (internodes).

We must now study buds more closely, and especially the resting buds, or winter buds, of trees and shrubs. In a resting bud growth does not go on continuously as in the case of the buds formed in the summer months, but is interrupted by a resting period, the winter, during which growth is almost at a standstill. In a resting bud the end of the shoot is in a young and as yet short and undeveloped state, and is surrounded by young leaves, both leaves and stem awaiting the conditions which will stimulate them to growth. Let us begin by examining a large bud, such as a Brussels Sprout, a Cabbage, or a Lettuce.

123. Cabbage, Brussels Sprout.—A Cabbage may be chosen for dissection, on account of its large size; Brussels Sprouts may be used for experiments where several specimens are required.

We pick off the leaves, starting with the outermost and lowest, and note that they are more or less tightly folded over one another and over the end of the stem which lies near the centre of the mass. The outermost leaves are attached lower down on the stem than the inner leaves, they are larger, they are more loosely packed and may be already expanding and spreading outwards, and the lower part of the stem shows distinct spaces (internodes) between the insertions of these outermost leaves. As we proceed with the dissection, removing each leaf close down to its insertion on the stem, the leaves are seen to be more and more closely packed, and smaller and smaller, as we approach the interior of the mass; also they are more delicate in texture, and no longer green like the outer leaves but white or yellowish. It becomes more and more difficult to remove the small delicate crowded young leaves, and at last we can see the tip of the stem as a rounded projection on which, with the aid of a lens, we can make out a number of small knobs (the beginnings of leaves) which are more and more minute in size on being traced upwards to the smooth apex or growing-point. It will be noted that each leaf, except the youngest ones just below the growing-point, has a bud in its axil.

We now cut the Cabbage or Sprout accurately down the middle, to get a longitudinal section which exactly halves the stem. This section shows clearly the axis giving off young leaves in such a way that the youngest leaves are nearest the tip of the stem, while the more developed leaves become successively further and further removed from the younger ones by the elongation of the internodes, and at the same time expand by the flattening out of the previously concave upper surface, by growth in size, and by elongation of the leaf-stalk—though the latter is not so marked here as in some other plants.

If we weigh (*a*) an entire Sprout, (*b*) one from which the large outer leaves have been removed, set both in a dry place, and weigh again after a day, we find that (*a*) loses more in weight than (*b*) does; the loss in weight is due to loss of water, hence we see that the older outer leaves protect the more delicate young inner leaves from losing moisture. That the outer leaves prevent light from reaching the young leaves, thus accounting for their lack of green colour, is easily proved by removing the outer leaves from two Sprouts, setting the two in water to keep them fresh, and placing one in darkness while the other is exposed to light.

The presence of vascular bundles can be shown by setting a Sprout in water coloured with red ink; the bundles in the stem, which may be seen in a section as hard strings, and in the leaves are coloured red after a time.

124. Winter Buds.—The buds formed at the close of the summer do not develop at once, but remain dormant during the winter. When a resting bud or winter bud is about to be formed the stem stops growing in length, while the last leaves on the shoot sometimes grow in the ordinary way, except that instead of spreading out as usual they remain curved inwards (owing to the lower side growing faster than the upper) and thus cover the young leaves formed higher up on the stem.

Naked resting buds of this kind—resembling a Brussels Sprout or a Cabbage in structure—are found in herbaceous plants in which the parts above ground die down so that the buds are produced at or below the surface of the soil, and also in water plants. When buds are formed below ground, as in plants with rhizomes or bulbs or corms, there is no need for any special protection, the soil in which they are buried keeps them warm and moist; the buds of water plants are fully protected by the water itself or by the mud at the bottom into which they sink in autumn; and where the buds are formed just above the surface of the ground they are often protected by the remains of dead leaves.

The conditions during winter are of course very different in the case of shrubs and trees, whose buds are exposed to the cold air and to drying winds, to mention only two of the dangers of the winter resting period. A glance at the buds of the majority of trees and shrubs shows that they differ from the simple type of bud seen in the Brussels Sprout, in which all the leaves are alike, or nearly so, and of the ordinary texture of green leaves. In the buds of most trees and shrubs the outer coverings of the bud are bud-scales, usually very different from the delicate young leaves inside, these scales being as a rule brown in colour, firm and hard in texture, and often covered with hairs or cemented together by gum or resin. Each scale is a leaf or part of a leaf; in fact, the scales are simply the outermost leaves of the bud, which, when the latter is first formed in autumn ready for the winter rest, become hard, tough and scale-like, and thus better adapted to protect the delicate parts inside. The chief danger to be guarded against is that of drying up, though the bud-scales also serve as a protection against frost and rain.

The naked (scaleless) buds of Cabbage and Brussels Sprout can, of course, withstand exposure in winter, and there are a few shrubs and trees with naked buds—*e.g.* Wayfaring Tree, Ivy. Not only can naked buds withstand a severe winter, but no covering of bud-scales can protect the inner parts of a bud from chilling during a long frost; moreover, removal of the bud-scales during winter may result in no damage from cold if care is taken that the exposed buds are not allowed to dry up.

From these facts we may infer that loss of water is not only as real a danger as the cold of winter, but is doubtless *the* great danger to be averted. That this is so may, in fact, be realised when we consider that during this period the roots are absorbing hardly any water from the soil and there is hardly any transpiration current flowing in the stem, hence loss of water at such a time would be fatal to the young shoot inside the bud. When a cold dry east wind blows after the buds have expanded in spring the young leaves are often killed, whereas an equally cold but moist west wind hardly affects them.

125. Horse Chestnut.—This tree is easily recognised in summer by its large compound hand-like leaves with usually seven leaflets, and its erect conical inflorescences, which later bear large prickly capsules; and in winter by its large leaf-scars and brown egg-shaped sticky buds.

Study twigs at different times throughout the year. In *summer* note (1) the arrangement of the leaves in crossed pairs; (2) the course of the branches—they ascend at first on leaving the main trunk, then bend downwards, and curve upwards again at the tip; (3) the tendency to formation of a leaf-mosaic at the end of each twig—the lower leaves have a longer stalk and larger leaflets than the upper leaves (Fig. 58); (4) the leaf-stalk has a broad base and is also broadened at the tip, where the leaflets are inserted; (5) the leaflets have a toothed margin and a sharp tip, just below which the leaflet is broadest; (6) the thick stem of the inflorescence bears in its lower part groups of about three flowers, but higher up the flowers arise singly.

In *autumn* note that (1) the ovary of some of the flowers has ripened into a large prickly capsule, which opens to let the large seeds escape; (2) eventually the whole inflorescence falls off, leaving a saddle-shaped scar at the end of the twig; (3) the leaves turn brown and fall off—each leaflet is detached from the top of the leaf-stalk in the same way that the latter is detached at the base from the stem itself.

In *winter* examine a cut twig (Figs. 69, 70) about three feet long, and note (1) the large *terminal bud*, sometimes replaced by the saddle-shaped inflorescence-scar; (2) the *lateral buds*, arranged in crossed pairs; (3) below each lateral bud a large flat *leaf-scar*, with outline like a shield or a hoof and showing a series of projecting *bundle-scars*; (4) a series of '*girdles* or zones at intervals along the twig, each girdle consisting of a number of closely set transverse scars—each side branch also shows one of these girdles at its base; (5) the *lenticels*, small rounded or oval raised patches scattered over the surface of the twig (Art. 98).

Fig. 69.—Twig of Horse Chestnut in Winter.

Girdle scars are not present in the photograph.

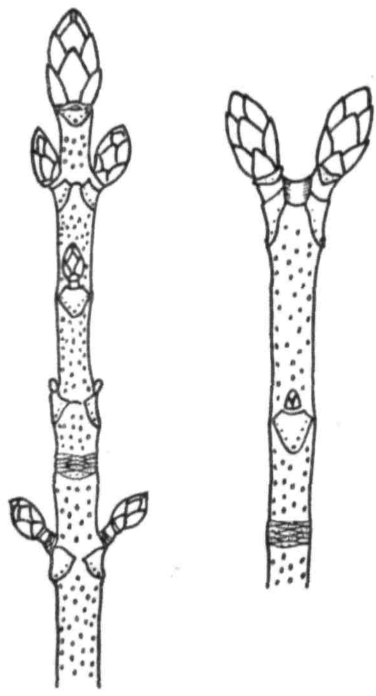


Fig. 70.—Twigs of Horse Chestnut.

Showing on the left a terminal bud, on the right the scar of an inflorescence; both twigs show lateral buds, leaf-scars, girdle-scars, and lenticels.

Dissect a bud, removing the parts in proper order and laying them out on a sheet of paper; the bud may be dipped in alcohol (methylated spirit) in order to remove the sticky resin cement-ing the scales together.[1] Note that (1) the bud-scales are arranged in crossed pairs; (2) the two outermost and lowest scales are smaller than those of the next pair, and these are followed by two or three pairs of still larger scales covering the top of the bud, all these outer scales being thick, hard, and brown; (3) within these we see a pair or two pairs of soft greenish scales; (4) the

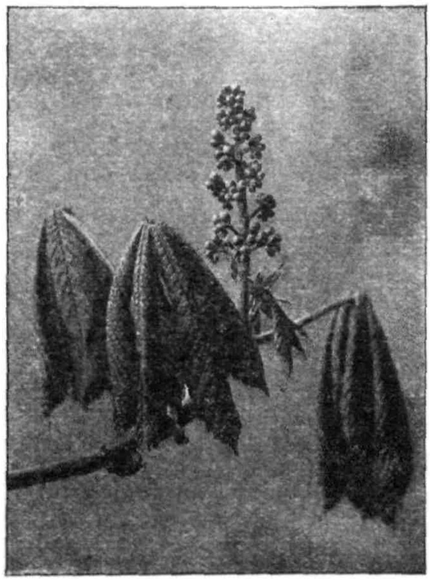


Fig. 71.—Twig of Horse Chestnut in Spring.

young foliage-leaves, densely covered with white woolly hairs, with each of the leaflets folded along its mid-rib; (5) in some buds there is a central young inflorescence.

In *spring* watch closely the opening of the buds (Fig. 71), which may be hastened by setting a cut twig in water in a warm

[1] In the Smooth-fruited Horse Chestnut the buds are not resinous, and the structure of the buds is therefore more easily made out.

room. Note that (1) the bud swells up; (2) the brown outer scales become loosened and bulged outwards; (3) the greenish inner scales grow in length and bend outwards—sometimes these scales show a tuft of small leaflets at the tip; (4) the young leaves emerge, with the leaflets folded along the mid-rib and also along the side-veins; (5) as the stalk of the leaf lengthens, the leaflets spread open and bend downwards; (6) the leaflets later rise upwards again and spread out horizontally; (7) each leaflet opens out along the mid-rib, and as it grows the folds along the side veins are smoothed out; (8) the axis or stem of the bud meanwhile grows in length, the pairs of leaves becoming spaced out on the soft green stem; (9) the bud-scales fall away, leaving a zone of closely set scars on the stem; (10) the white hairs covering the young leaves become brown and fall away, saving a few which remain at the top of the leaf-stalk; (11) if the bud contains an inflorescence, the axis of this elongates and the flowers enlarge and eventually open.

Further observation will show that (1) the lateral buds appear at a very early stage in the axils of the unfolding foliage-leaves; (2) the axis of the young shoot becomes hard and brown as it grows in length and thickness; (3) the lenticels appear as small raised flecks, which grow larger and become oval or rounded.

During summer the axillary buds, which were visible in spring, grow larger and eventually become winter buds, though some of them grow very little and remain as dormant buds. The young buds may be caused to grow into shoots a year before the proper time, by either pulling off the leaves from the young twig or by cutting across the latter. This precocious growth of the buds sometimes occurs naturally, producing the so-called "Lammas shoots," owing to such causes as the destruction of the young leaves by dry cold spring winds.

From the foregoing observations we see that a bud consists of a short condensed stem bearing leaves and in some cases an inflorescence; the internodes of the stem are very short, hence the young leaves are closely packed together. The bud-scales in Horse Chestnut are the bases of leaves, the upper part of which does not usually develop—this is shown by the occasional presence of *leaflets* at the tip of the inner bud-scales. Since the scales, on falling away in spring, leave scars on the lower part of the bud-axis and this part remains short, we get zones of closely set scars, sometimes called "girdle-scars" or "ring-scars." A zone is of course seen at the base of each branch, and on looking along the main twig and its branches we can easily tell how much the twig has grown each year for several years back.

126. Beech.—This is easily known by its smooth grey bark, ovate entire leaves fringed with hairs when young, long brown tapering buds, and three-sided nuts in pairs within a four-lobed spiny cup.

The leaves are in two rows, and on horizontal or inclined branches the leaves have the stalk twisted so that the blades all present their upper faces to the light. The blades are usually symmetrical, tapering above and below, with conspicuous pinnate veins.

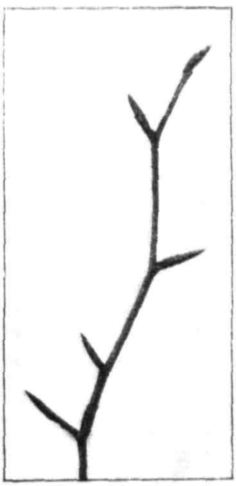


Fig. 72.—Twig of Beech in Winter.

Form is cylindrical, slender, angled, not straight; buds at angles, long and tapering, alternate; ring-scars well marked.

Besides the ordinary long branches there are dwarf shoots which grow very slowly and show crowded "girdle-scars" (zones of bud-scale scars) which indicate the small annual growth in length. On a branch the long and short shoots are arranged in such a way that the leaves form a close mosaic and catch a large amount of light.

The slender zigzag twigs (Fig. 72) have the buds standing out at an angle of about 60°. The buds are usually displaced to one side of the axil of the small leaf-scars (which show three bundle-scars), and are covered by brown scales arranged in four rows. The outermost scales are broad and short, but those further in are longer, narrower, and thinner. The first seven or eight pairs of scales have no leaves, but the innermost pairs have a small leaf between them, then come the folded-up young leaves with their stipules, densely covered with silky hairs. In this case the bud-scales are stipules of leaves whose blade remains undeveloped—this is more clearly seen on examining the opening buds.

The opening of the buds should be very carefully watched from day to day. As the bud swells up and its stem grows in length, the outer scales are pushed outwards and the young leaves emerge from the tip of the bud. The foldings of the leaf-blades are gradually smoothed out, the stipules fall off after having fulfilled their duty of protecting the young leaves, and the hairs on the leaves become shrivelled and disappear—the fringe of hairs at the margin of the leaf persists for a fairly long time after the rest have gone.

The flowers are not visible in the resting bud, but appear later in the axils of the young leaves. The male and female flowers are borne separately on long-stalked and nearly globular inflorescences; usually the pendulous male inflorescences are in the axils of the lower leaves, and the female inflorescences, which have shorter and stouter stalks enabling them to stand erect, arise in the axils of the higher leaves.

The winter buds of various other trees and shrubs should be studied. When the buds are rather small, making it difficult to see the structure and arrangement of the parts, much is learned by carefully watching the stages in the opening of the bud in spring, and by combining this with observations made at other times of the year.

127. Bud-scales.—The bud-scales are well adapted for their function of protecting the young leaves within them, for they are usually thick, hard, corky, gummy, resinous, or hairy, or may show several of these characters together. The scales may represent whole leaves (Privet, Lilac), or leaf-bases without stalk or blade (Sycamore, Horse Chestnut, Cherry, and many others), or stipules of leaves which also develop a blade (Alder, Elm, Hazel), or stipules of leaves without a blade (Beech, Oak).

It is interesting, and usually quite easy, to find out the real nature of the bud-scales when examining opening buds in spring. For instance, in some cases the scale bears at its tip a more or less developed blade; every transition from a mere leaf-base to scales with a small or large blade at the tip may be seen in the Cherry, and it is well worth while to dissect an opening Cherry bud, picking off and laying out in proper order first the outer scales and then the transitional blade-bearing scales, and finally the young leaves, and making sketches of these.

128. Vernation.—This term is applied to the form of the young leaf in the bud. It is not necessary to learn the names given to the different ways in which the young leaves are folded, though these names are mentioned here so that they can be identified in the accompanying figure (Fig. 73).

To ensure the close packing of the leaves in the bud each leaf is usually folded up, and Fig. 73 shows the different appearances seen on cutting across the young leaf. Sometimes the leaves are nearly flat (Privet, Holly, Ivy, Willows), but more often they are folded. The leaf may be simply doubled up along the

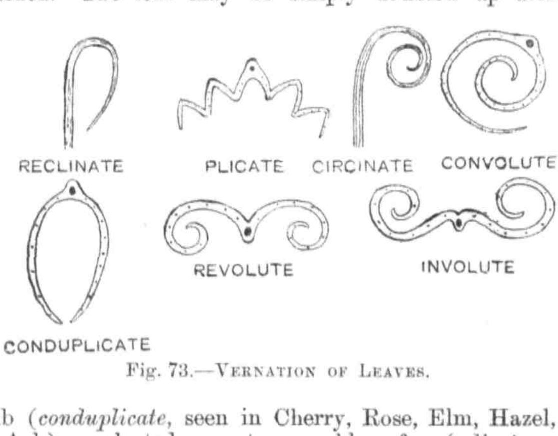


Fig. 73.—Vernation of Leaves.

mid-rib (*conduplicate*, seen in Cherry, Rose, Elm, Hazel, Oak, Lime, Ash), or pleated so as to resemble a fan (*plicate*, seen in Beech, Birch, Hornbeam, Maple, Sycamore); or the edges of the leaf may be rolled inwards, *i.e.* towards the upper side (*involute*, seen in Poplar, Apple, Pear), or the edges may be rolled outwards, *i.e.* towards the lower side (*revolute*, seen in Plane and Rhododendron), or the leaf may be rolled up from one side so that one edge of the leaf is within the coil and the other outside (*convolute*, seen in Plum and Blackthorn).

129. Opening of Winter Buds.—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 or stem, and since this part remains short, a series of closely crowded scars is left on the stem. A set of these bud-scale scars, or "girdle-scars," is of course seen at the base of each branch, and by examining a twig and noting these sets of scars we can easily tell how much the twig has grown in length each year, often for many years back; later on these marks are lost owing to the formation and casting-off of the bark, but in smooth-barked trees one can trace the growth back for thirty years or even more by means of these girdles of scars left by the bud-scales each spring.

As the stem of the bud elongates, the leaves grow in size and spread themselves out—the leaf-stalks of course helping in this if present—and become spaced out on the shoot. Buds then appear in the axils of the leaves, and these may either develop at once or after remaining dormant for some time, or they may become the resting buds for next year's growth.

130. Dormant Buds.—Some of the buds do not develop at once into branches, and it is easy to see why this is so. If all the buds developed, the leaves would be too closely packed together, and sufficient light could not reach them all. Again, buds that have been formed at the base of a shoot may get no chance of opening at the usual time because the struggle for water and food-supplies results in their being left unprovided, the available stores being taken by the other buds. These starved buds do not always die, but may remain dormant for years, capable of active growth when their opportunity comes.

Such buds may, years after their formation, be awakened to activity by various causes. For instance, part of the shoot, now thickened and developed into a branch, may be removed by pruning, or broken off by the wind or by the weight of snow; or the foliage may become exposed to better conditions as to food-supply, as when a tree previously shaded by others is suddenly freed and its leaves exposed to more light and air by the falling of the neighbouring trees. Under such conditions shoots grow out from the bare stems of various trees, and in most cases these shoots have arisen from dormant buds which were formed years ago but which were unable even to grow into a dwarf shoot. Such a dormant bud, so long as it remains connected with the wood of the parent stem, may live for many years, elongating just sufficiently to keep its head at the surface of the stem.

Belated shoots arising in this way are often in tufts, evidently owing to the fact that the primary dormant bud during its years of suppressed life has produced a number of minute buds in the axils of its scales and its lower leaves, so that when the time comes there is at each such place on the stem a number of buds ready to grow out into branches.

131. Adventitious Buds.—Quite apart from dormant buds, there are various cases in which shoots are formed from different parts of a plant, their origin being often, though by no means always, the outcome of injury. For instance, when a tree is felled, or when the base of the trunk is severely damaged, shoots are often formed from the healing tissue (callus) formed over the wound. Shoots often arise from the roots of trees and shrubs, in some cases quite apart from injury, in other cases only if the tree or shrub has been felled or otherwise injured; these shoots often spring up at a considerable distance from the tree or from the spot where it formerly stood. The production of adventitious shoots of this kind is easily studied in Hawthorn: if a piece of root is dug up and chopped into bits, which are covered loosely with damp soil, shoots are soon formed from the bits of root. Adventitious buds may also be formed on leaves: if entire leaves of Begonia, or pieces of the leaves, are placed on damp soil, buds appear which grow into new plants.

CHAPTER XII.

FLOWERS AND THEIR WORK.

132. The Work of the Flower.—We have already examined the Broad Bean flower, and have seen that after a time nothing is left of the flower except (1) the ovary which develops into the pod and contains the young seeds, and (2) the calyx which remains as a cup round the bottom of the pod. Evidently the function of the flower is to produce seeds.

In examining flowers we notice a powdery substance (pollen) which is produced in the anthers and is set free when they open. If we experiment with large flowers like Tulip or Wallflower we can prove that the pollen is essential for the production of seeds. We open a quite young flower, the anthers of which have not yet burst open, and remove the anthers; then to prevent pollen from reaching the pistil from another flower we tie a small bag of paper or fine muslin over the antherless flower. Again, if we cover the stigma of a flower with plasticine we find that no seeds are formed. Evidently, then, seeds are not formed, in most plants at any rate, unless pollen is placed on the stigma of the pistil—that is, unless pollination occurs.

Hence the only parts of the flower which are actually essential for seed-production are the stamens and the pistil, or more exactly the pollen-grains contained in the anthers and the ovules contained in the ovary.

133. 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 when self-pollination occurs.

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. There is, therefore, an obvious advantage to the species in securing cross-pollination, and we find many adaptations, some of them very remarkable, which favour cross-pollination and hinder self-pollination.

134. 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. Wind-pollination will be dealt with later (Art. 156). In this country insects are probably the only animals concerned in carrying pollen from flower to flower, but in some foreign plants pollination is effected by birds (especially humming-birds), bats, and even snails.

135. 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 flower previously some pollen will 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 flower.

The bee visits the Broad Bean flower in order to obtain honey, or nectar, a sugary liquid contained in the lower part of the stamen-trough, and if we watch the bee carefully we see that it pokes its tongue (proboscis) into this part of the flower, below the free stamen. In some flowers the honey-producing glands (nectaries) are conspicuous structures, and in some cases the honey is produced in such abundance that we can taste it and find that it is sweet.

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 which is emitted by 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.

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.

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.

136. 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.

137. Functions of the Corolla.—We have seen how the standard and the wings help in attracting bees to the flower, and how the wings work with the keel in causing the bee to carry away pollen as well as to bring pollen from other Bean flowers to the stigma. The keel by enclosing the stamens prevents rain from spoiling or washing away the pollen, and protects it from being shaken out of the flower by wind; it also prevents the nectar from being reached by useless insects, from loss by evaporation, and from being diluted or washed out by rain. The protection of the nectar is made still more complete by its being formed inside the stamen-trough.

138. The Parts of the Flower.—A flower may be regarded as a special kind of shoot, in so far as it consists of an axis or stem portion which bears appendages. The axis or *receptacle* (also called "torus" or "thalamus") appears as the swollen end portion of the flower-stalk when this is present, but many flowers have no stalk. In the flowers of most plants there are four kinds of appendages or flower parts. 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.* Narcissus).

Fig. 74. FLOWER OF ASH.

Some flowers, however, have a perianth which is composed of a single ring or series of parts only, while others are naked and have no perianth at all, *e.g.* Grasses (Fig. 138), Ash (Fig. 74), Arum (Fig. 75).

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 (Fig. 76). Flowers which have no carpels are said to be "male" or staminate, those without stamens are "female" or carpellary (pistillate).

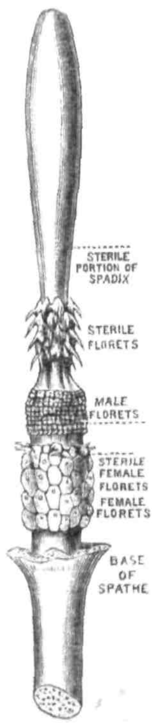


Fig. 75.—SPADIX OF ARUM.
Spathe removed to show the Flowers.

139. 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,

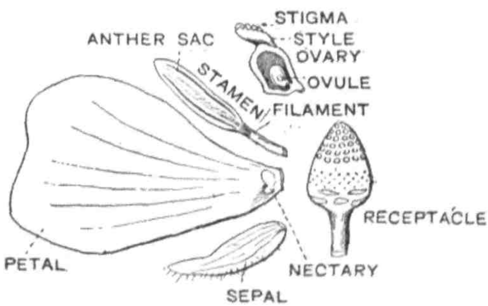
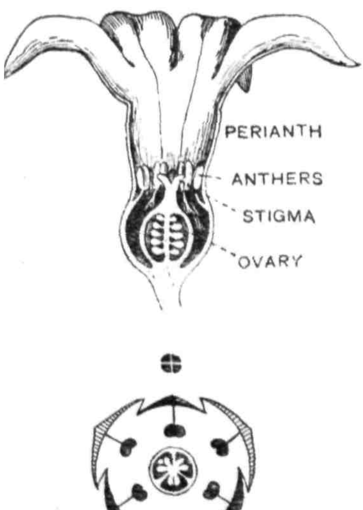


Fig. 76.—THE PARTS OF A BUTTERCUP FLOWER.
The points of insertion of the different parts are diagrammatically represented on the receptacle.

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, Hyacinths (Fig. 77), Iris (Fig. 78), Crocus (Figs. 63, 79), etc., the perianth is *gamophyllous*, consisting of a lower tubular part and six free lobes. In Daffodil



ig. 77.—Longitudinal Section and Floral Diagram of Flower of Garden Hyacinth.

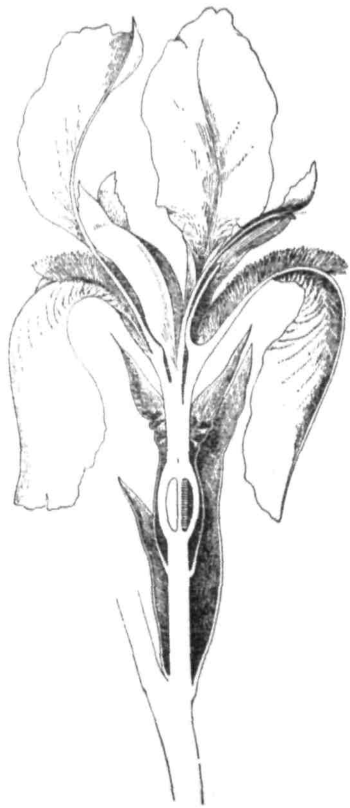


Fig. 78.—Vertical Section of Flower of Iris. (After Church.)

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.

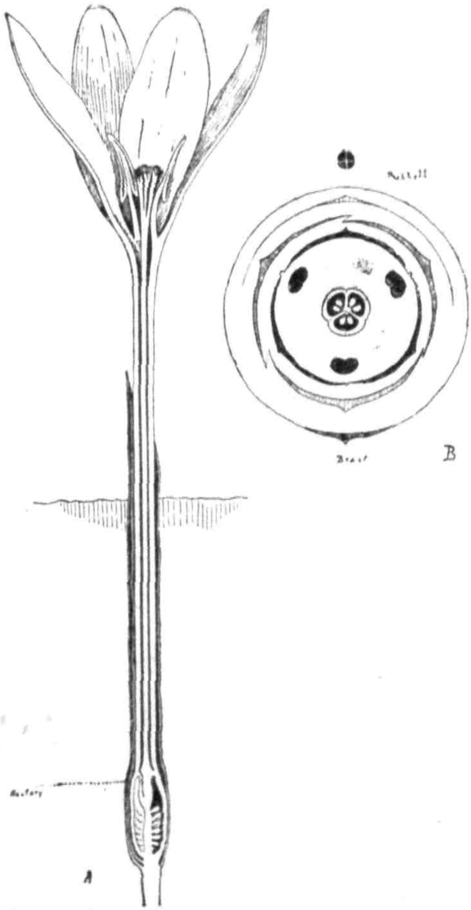


Fig. 79.—Vertical Section of Flower and Floral Diagram of Crocus. (After Church.)

and Narcissus, besides the tube and the lobes, there is a collar-like outgrowth or *corona* at the mouth of the perianth-tube. In Orchids (Fig. 80) one of the inner perianth-lobes, called the *labellum*, is of a different shape from the rest, and is usually the most conspicuous part of the flower.

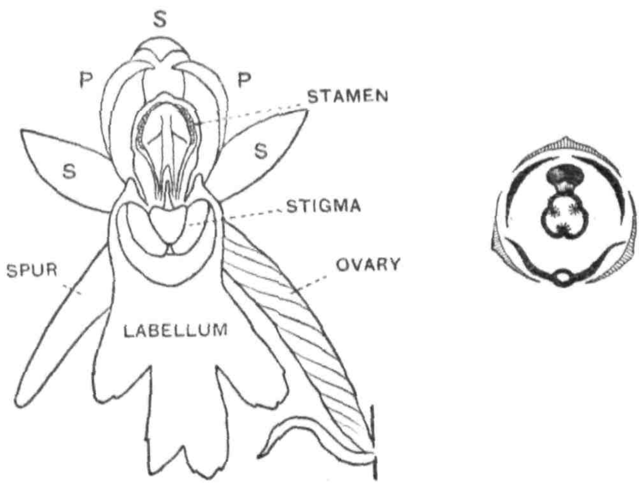


Fig. 80.—FLOWER (FRONT VIEW) AND FLORAL DIAGRAM OF ORCHIS.

140. Calyx.—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.

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 be absent (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 (Fig. 81), Winter Aconite, Christmas

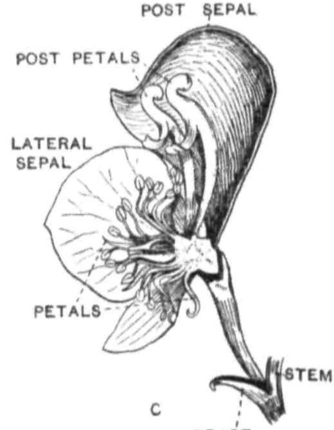


Fig. 81.—Longitudinal Section of Flower of Monkshood.

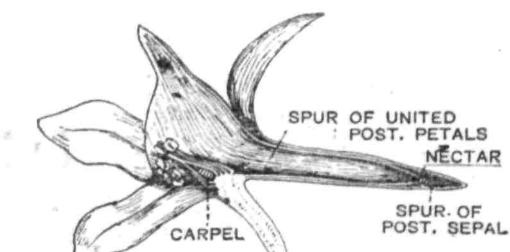


Fig. 82.—Longitudinal Section of Flower of Larkspur.

Rose, Larkspur (Fig. 82), and Marsh Marigold are brightly coloured, and take on the attractive function of the corolla. In the Wallflower (Fig. 83) the two outer sepals are slightly pouched at their bases, so that they may retain the nectar secreted by the glandular swellings placed beneath the bases of each of the two shorter stamens.

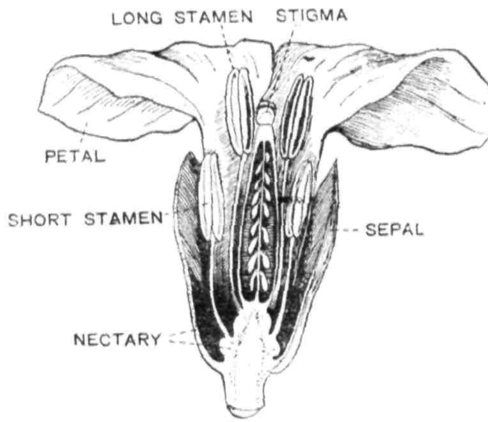


Fig. 83.—Vertical Section of Wallflower.

141. Corolla.—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 usually withers and falls away.

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*. The petals of the Pink have a scaly outgrowth (ligule) at the junction of the claw and limb.

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 (Fig. 76) 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 modified petals, as are the two posterior ones of the Monkshood (Fig. 81).

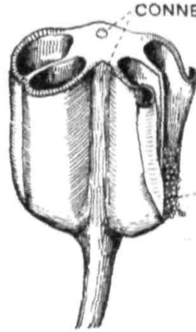


Fig. 84.—An Anther with the top cut off.

The right anther lobe is represented as being dehisced.

142. 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 a couple of 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. 84).

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 (Fig. 85), Heaths (Fig. 86), Milkwort, etc., small pores are

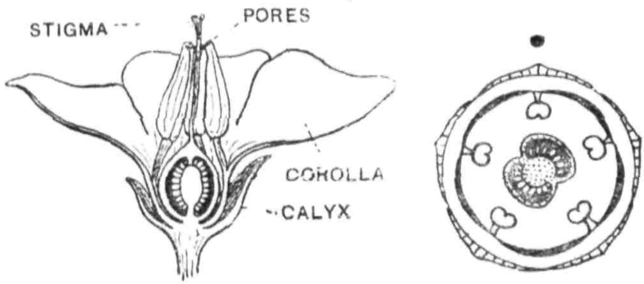


Fig. 85.—Longitudinal Section and Floral Diagram of Flower of Potato.

Fig. 86.—Inflorescence and Longitudinal Section of Flower of Cross-leaved Heath (Erica tetralix).

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.

143. 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. 87), 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

Fig. 87.—Carpellary Leaf with Marginal Ovules.

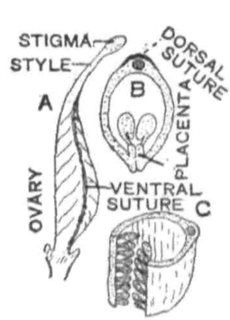


Fig. 88.—The Monocarpellary Pistil.

A, Entire; B, Transverse section of Ovary; C, Indicates the method of folding.

grew together along a line known as the ventral suture, which bears a double row of ovules derived from the two margins of the leaf.

The purpose of this change is immediately obvious, for the young ovules are now protected within a hollow chamber known as the *ovary* (Fig. 88), 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, forming the receptive surface for the pollen. The dorsal suture of the carpel corresponds to the mid-rib of a leaf; the cushion of tissue along the ventral suture, from which the ovules arise, is known as the *placenta*.[1]

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.

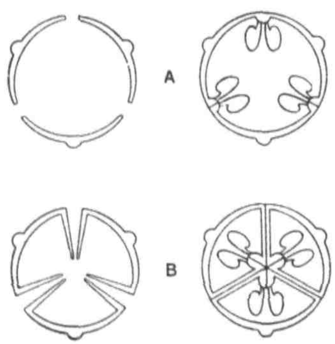


Fig. 89.—Diagram of Syncarpous Ovary, with Parietal (A) and Axile (B) Placentation.

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. 89, A); but when the ovules arise from the longitudinal axis in the centre of the ovary the placentation is said to be *axile* (Fig. 89, B), *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

[1] In the Water-lily, Flowering Rush, and a few other plants the ovules are scattered all over the inner surface of the carpels.

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*, and it is probably a modified form of axile placentation, in which the dividing septa do not develop; this is probably not a primitive condition, but a secondary adaptation, the attachment being such that the ovule is more readily provided with food.

The only safe way of determining the number of carpels in a syncarpous gynecium is by studying its development and noting how many leaf-rudiments fuse to form it. Adult flowers, however, often afford evidence of value to beginners. Thus 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 the Labiate and Borage families, 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, although in the case of the Water-lily the inner surfaces of the carpellary compartments of the ovary are studded with ovules. 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 leaves.

144. Cohesion and Adhesion of Flower Parts.—"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 and stigmas sometimes 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).

145. Perigyny and Epigyny (Fig. 90).—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*. 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:—

(1) The petals tend to unite, as also do the sepals, thus producing flowers of very specialised character (generally in connection

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

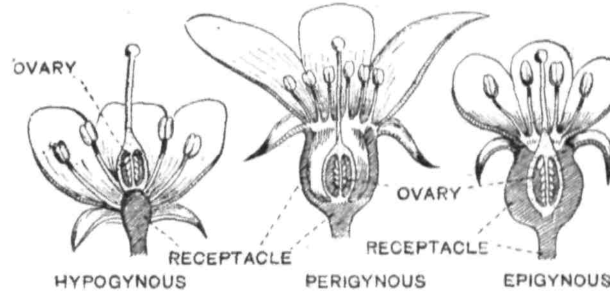


Fig. 90.—Vertical Sections of Flowers, showing different forms of the Receptacle.

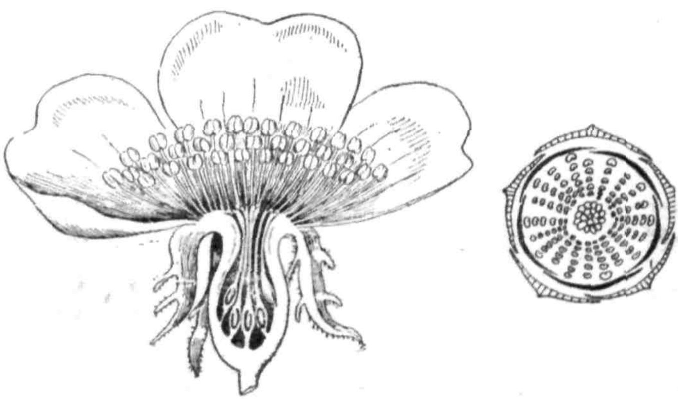


Fig. 91.—Longitudinal Section and Floral Diagram of Flower of Dog Rose.

encloses and protects the carpel or carpels, leaving the stigma exposed at the end of the style, *e.g.* Cherry, Rose (Fig. 91). 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 (Fig. 92). In perigynous flowers the pistil is

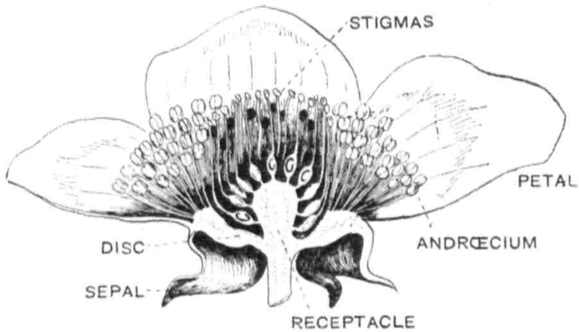


Fig. 92.—Longitudial Section of Flower of Blackberry (Bramble).

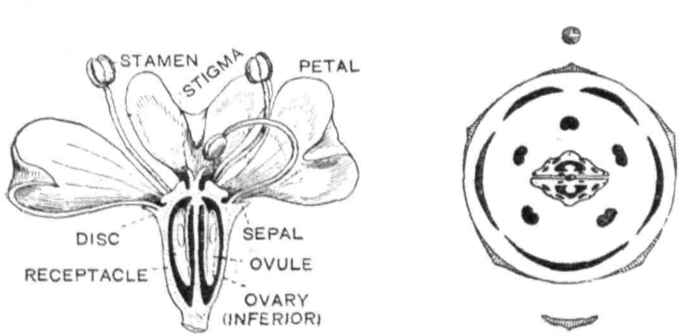


Fig. 93.—Vertical Section and Floral Diagram of Flower of Cow Parsnip.

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 remain-

ing free. Here the ovary is said to be *inferior* and the flower **epigynous,** *e.g.* Umbelliferae (Fig. 93), Iris (Fig. 78), Crocus (Fig. 79), Orchids (Fig. 80). The ovary is thus protected, and an increased surface is offered for the passage of food to the developing ovules from the receptacle.

146. Nectaries.—The receptacle frequently bears a fleshy or glandular outgrowth, such as is found on the top of the inferior ovary in Umbelliferae (Fig. 93) and in Ivy, or around the base of the ovary in Dead-nettle (Fig. 129), Snapdragon, etc. This is

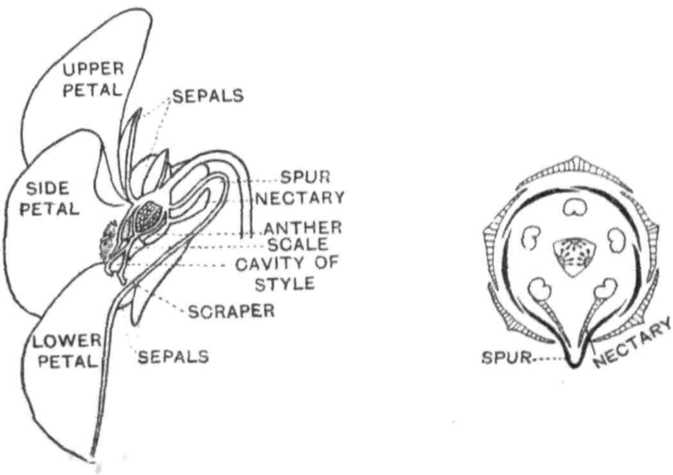


Fig. 94.—Longitudinal Section and Floral Diagram of Violet.

sometimes termed the "disc." In the Blackberry the disc lines the outer concave part of the receptacle. Very commonly the disc is lobed (Wallflower), and frequently it secretes nectar. Nectaries may, however, develop from, or upon, any part of the flower. Thus in the Violet (Fig. 94) the appendages borne by two of the stamens secrete nectar into the hollow spur of the anterior petal. In the Buttercup the kidney-shaped projection at the base of each of the petals covers a small gland, while the petals of the Christmas Rose are represented by hollow tubular nectaries.

Examine and sketch the nectaries of the following flowers: Buttercup, Lesser Celandine, Christmas Rose, Winter Aconite, Monkshood, Larkspur, Violet, Pansy, Dead-nettle, Snapdragon.

147. Symmetry of the Flower.—Nearly all flowers are symmetrical, *i.e.* can be divided into two corresponding halves. When a flower can be so divided along one plane only it is said to be bilaterally symmetrical or *zygomorphic*, but when it 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").

148. 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 represent correctly 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. 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 in. 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. To cut a flower longitudinally through the middle it is usually best to begin the cut at the base of the flower.

149. 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 flowers. The signs ♂, ♀, ☿ respectively denote staminate, carpellary, and hermaphrodite ("perfect") flowers. The letters K, C, and P represent the calyx, corolla, and 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 floral formulas will serve as illustrations:—

Buttercup .... $\oplus K5, C5, A\infty, G\underline{\infty}$.

Narcissus .... $\oplus \overbrace{P(3+3), A3+3}, G\,\overline{(3)}$.

Violet.............. $\dagger K5, C5, A5, G\,\underline{(3)}$.

Dead-nettle ...... $\dagger K(5), \overbrace{C(5), A2+2}, G\underline{(2)}$.

Stitchwort ...... $\oplus K5, C5, A5+5, G\,\underline{(3)}$.

150. 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 terminal, as in Tulip and Daffodil, or may arise in the axils of ordinary leaves, as in the Scarlet Pimpernel and Money-wort. Such flowers may in some cases (*e.g.* Violets and Pansies, where the stalk bears two small bracts) be regarded as reduced inflorescences, in which the main axis remains unbranched and only one flower develops. 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 instead of the numerous ones which characterise most racemes.

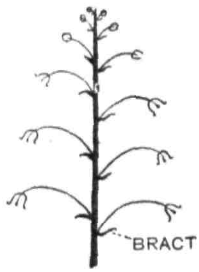


Fig. 95.—RACEME.

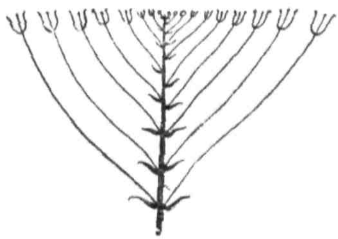


Fig. 96.—CORYMB.

The order of flowering usually follows the order of development, and hence the flowering in racemes is generally centripetal, whereas that of cymes is on the whole centrifugal. That is, 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), while in the second case the youngest flowers are nearest the base or the outside of the inflorescence.

Fig. 97.—SPIKE.

The **raceme** (Fig. 95) consists of an elongated axis which bears stalked flowers (stalks about equal in length), *e.g.* Foxglove, Hyacinth. 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** (Fig. 96): axis elongated, flower-stalks unequal in length, bringing the flowers to about the same level (Candytuft); (2) **Spike** (Fig. 97): axis elongated, flowers sessile (Plantain, Orchids); (3) **Catkin:** a spike bearing unisexual flowers of one kind (Willow, Hazel); (4) **Spadix** (Fig. 75): a spike with fleshy axis, usually bearing unisexual flowers enclosed by a large bract, the **spathe** (Arum); (5) **Simple umbel** (Fig. 98): axis shortened, flowers stalked (Cowslip); (6) **Capitulum** (Fig. 99): axis shortened and expanded, flowers sessile (Composites).

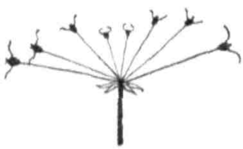


Fig. 98.—A Simple Umbel.

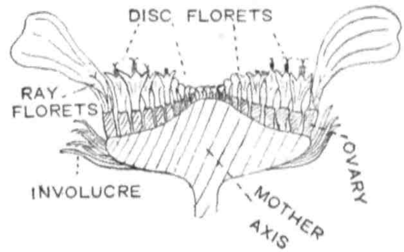


Fig. 99.—Capitulum (Vertical Section).

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 (Fig. 100), Red and Yellow Gentians; or in whorls of three or more **(multiparous cyme)**—*e.g.* Elder.

Fig. 100.—Dichasium or Biparous Cyme.

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, Bird's-foot Trefoil, etc.), Umbellifers, Ivy, Dogwood, Elder, Valerians, Scabious, Sheep's-bit, Compositae, etc.

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** (umbel of umbels), in most Umbelliferae (Fig. 101).

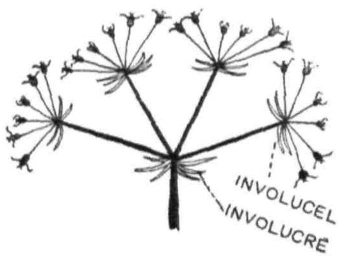


Fig. 101.—Compound Umbel.

151. 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-fertilisation 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. We have this condition in its extreme form where the staminate and pistillate flowers are on different plants (*e.g.* Willow). Some plants are self-sterile, *i.e.* the flower cannot be fertilised by its own pollen.

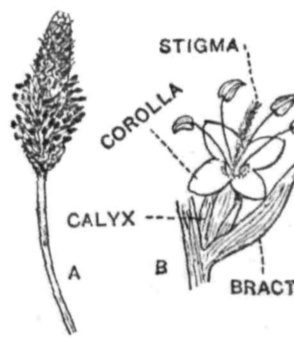


Fig. 102.
A, Spike; B, Flower of Plantain.

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 protandry are found in Composites, Labiates, Harebells, Ivy, Umbellifers, Willow-herbs, etc.; of protogyny in Plantains (Fig. 102), Woodrush, Figwort (Fig. 103), Hawthorn, etc.

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. 155.)

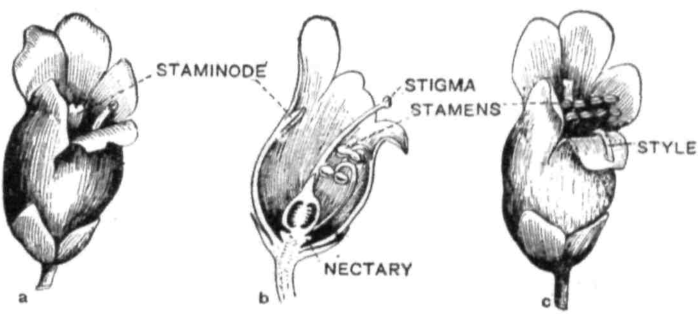


Fig. 103.—FIGWORT (SCROPHULARIA).

a, Flower when first opened; b, Longitudinal section of same; c, Flower a day or two later. In c the style and stigma are now withering, while the anthers are exposed and about to open.

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 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); or the stamens may be jerked and the pollen scattered over the insect's body (Barberry).

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.

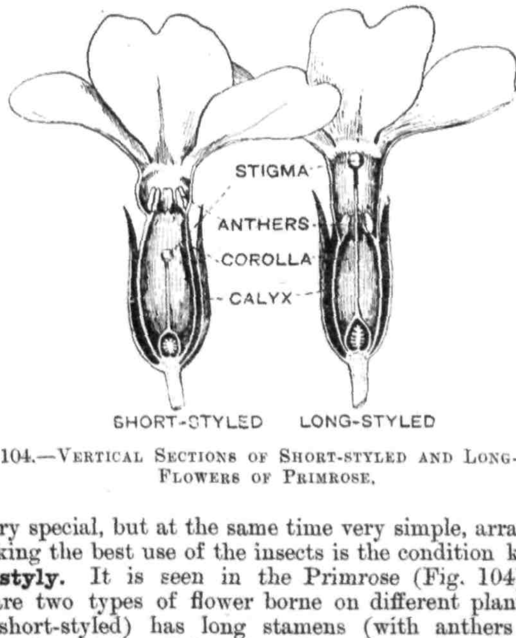


Fig. 104.—Vertical Sections of Short-styled and Long-styled Flowers of Primrose.

A very special, but at the same time very simple, arrangement for making the best use of the insects is the condition known as **heterostyly.** It is seen in the Primrose (Fig. 104). Here there are two types of flower borne on different plants. One kind (short-styled) has long stamens (with anthers in the throat of the corolla tube) and a short style; the other (long-styled) 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 Purple Loosestrife (Lythrum) there are three forms of flower—with long, short, and medium styles and stamens (the latter in two whorls).

152. 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.* Compositae).

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.* Violets, Wood Sorrel.

In our study of flower-mechanisms we should remember that self-pollination occurs regularly in most flowers where it is not precluded by dioecism, complete dichogamy, or self-sterility, and that although inferior to cross-pollination in its results it is always better than *no* pollination.

153. 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 or 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.

Flowers may be arranged in various biological groups or classes according to their adaptations for insect-visitation :—

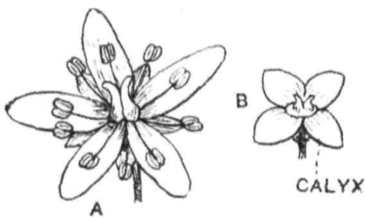


Fig. 105.

A, Flower of a Saxifrage ; B, Flower of *Chrysosplenium* (Golden Saxifrage).

(1) **Flowers adapted for Short-tongued Insects.**—These may be (*a*) flowers in which the honey is freely exposed on the surface, *e.g.* Ivy, Umbelliferae (Fig. 93), Golden Saxifrage (Fig. 105), etc. ; (*b*) flowers with a very short tube, *e.g.* Moschatel, Bedstraw, Enchanter's Nightshade (Fig. 106) ; (*c*) shallow open flowers such as Stonecrop and Saxifrages. Such flowers are visited by the shorter-tongued beetles and flies.

(2) **Flowers with partially concealed Honey.**—This group includes flowers in which the honey can be reached only by insects with tongues at least 3 mm. in length, and which are therefore visited by the longer-tongued beetles and flies, as well as by insects of higher type. The honey may be slightly concealed by the stamens, *e.g.* Buttercup and Stitchwort ; by the erect stiff sepals, as in the smaller Cruciferae ; by the formation of a shallow calyx-tube, as in many Rosaceae (*e.g.* Strawberry) ; by a short corolla-tube, *e.g.* the shorter-tubed Compositae, Guelder Rose, etc.

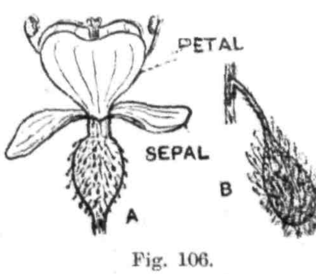


Fig. 106.

A, Flower ; B, Fruit of Enchanter's Nightshade.

(3) **Flowers with fully concealed Honey.**—This type of flower differs only in degree from the last. Here the honey can

only be reached by insects having tongues about 6 mm long, including the longest-tongued flies (chiefly hover-flies), the shorter-tongued bees, and wasps. The concealment of the honey is effected by a further deepening of the flower, owing to the formation of a calyx-tube, to the calyx being gamosepalous or the corolla gamopetalous, or to other causes. Examples of these medium-tubed flowers are seen in the Blackberry (Fig. 92), Currants, Gooseberry (Fig. 107), Willow-herb (Fig. 108), Geranium, Speedwell, etc. The Figwort, Snowberry, and Barberry are examples of flowers largely visited by wasps.

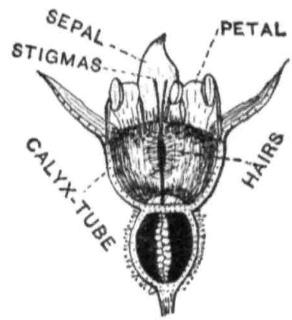


Fig. 107.—VERTICAL SECTION OF FLOWER OF GOOSEBERRY.

(4) **Long-tubed Flowers.** — When the flower-tube becomes longer, all the shorter-tongued insects are more or less completely excluded, and the flower is adapted for, and chiefly visited by, the larger bees, butterflies, and moths. Many flowers belonging to the Lily, Daffodil, and Iris families of Monocotyledons, in which the perianth nearly

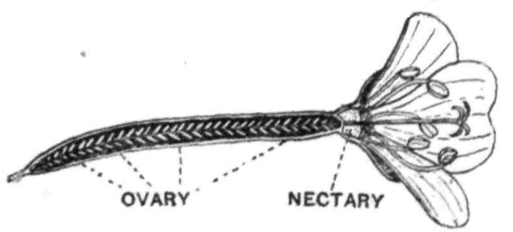


Fig. 108.—VERTICAL SECTION OF FLOWER OF WILLOW-HERB.

always forms a long tube, come under this type. 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.

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 broods. Humble-bees have longer tongues than hive-bees, and 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.

(5) **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,

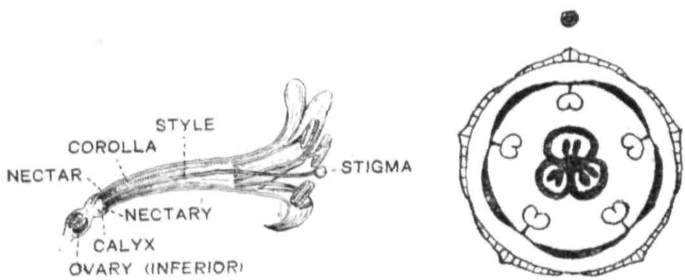


Fig. 109.—Longitudinal Section and Floral Diagram of Flower of Honeysuckle.

though they may visit the flower for pollen, or the humble-bee may bite through the tube (calyx or corolla) and thus rob the flower of its honey. Good examples of butterfly flowers are seen in the Pinks, Red Campion, Corn-cockle, but butterflies also visit many flowers which are adapted for bees, *most* butterflies and moths having tongues of about the same length as, or a little longer than, those of bees.

Some moths, however, have far longer tongues (30 mm or more in British species), which are (as in butterflies) carried coiled up in a spiral under the head when flying. These moths can reach honey when it is at the bottom of a very long tube, as in the Honeysuckle (Fig. 109), which is visited chiefly by the night-flying Privet Hawk-moth. Other flowers pollinated by night-flying moths are the White Campion, Evening Primrose (Fig.

110), Tobacco Plant, and Privet. Moth-pollinated flowers are white or pale-coloured, sweetly scented, and open in the evening, usually remaining closed and almost scentless during the day.

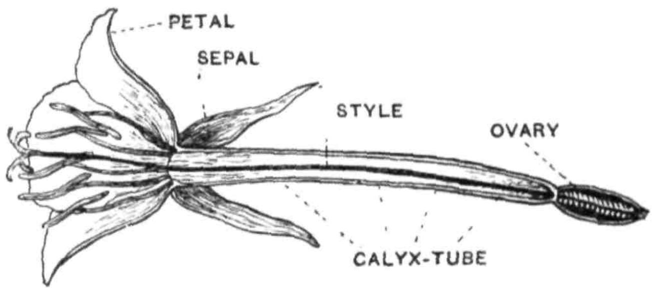


Fig. 110.—Vertical Section of Flower of Evening Primrose.

154. 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, 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.

155. 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. 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 drooping position, *e.g.* Heaths, Bluebell, Lily of the Valley, Solomon's Seal; in some cases the stalk droops at night or in bad weather, *e.g.* Wood Sorrel; or the flower closes up under similar conditions, *e.g.* Tulip, Crocus, Lesser Celandine, Scarlet Pimpernel, 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. 78) the large petaloid stigmas cover the stamens, while in Orchis (Fig. 80) the single stamen is covered by a hood formed by one of the sepals and two of the petals.

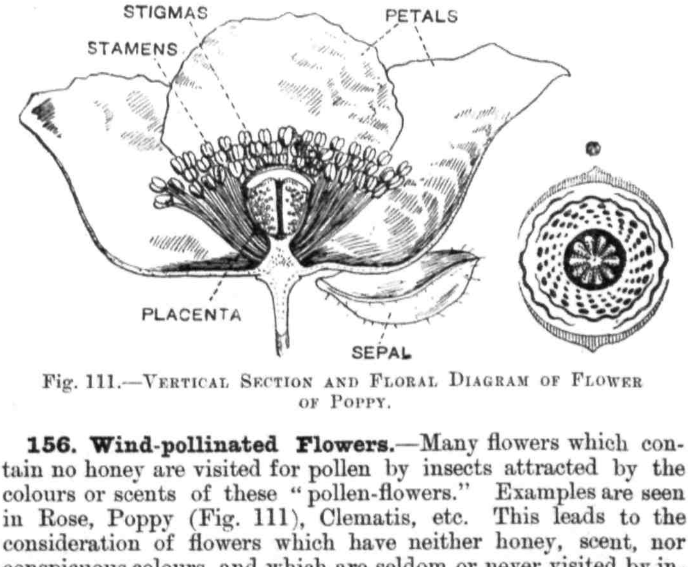


Fig. 111.—Vertical Section and Floral Diagram of Flower of Poppy.

156. 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." Examples are seen in Rose, Poppy (Fig. 111), Clematis, etc. 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.[1]

[1] 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.

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 (Fig. 102), 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.

CHAPTER XIII.

FRUITS AND SEEDS.

157. How Fruits are Formed.—Fruit is developed from the flower as the result of fertilisation of the ovule or ovules in the ovary. Fertilisation is followed by various changes in the parts of the flower. The anthers and the stigma, the parts more immediately concerned in the process of fertilisation, are the first to wither and decay, though the style if present may persist and even grow and become modified so as to help in seed-dispersal. The flower-leaves become dry in most cases, the petals falling off, while the sepals may also fall off or may persist in an altered form. The ovary becomes enlarged, its wall forming the pericarp, and the ovules develop into seeds containing the embryo plant.

The term fruit is strictly applied to the mature pistil or ovary containing the seeds, but it often includes other parts of the flower, and even parts other than the flower itself. For instance, the fruit of Hazel consists of the ovary enclosed by the bracts; that of the Apple consists of the ovary and flower receptacle; that of the Pine-apple consists of the whole inflorescence. That is to say, a wide definition of fruit would include all those parts which show a striking change as the result of fertilisation other than merely withering. As a general rule the fruit does not ripen unless fertilisation has taken place and the ovary withers; but cases occur, chiefly as the result of cultivation, in which the fruit swells up and becomes to outer appearance mature, though no seeds are produced (seedless Oranges, Grapes, Pine-apples), while in Bananas the non-formation of seeds leads to greater growth of the fruit.

158. Changes in Development of Ovary into Fruit.—The fruit, like the ovary, may be formed of a single carpel or of several carpels, and it may have one chamber or several chambers. In many cases it is easy to observe the changes that occur as the ovary in converted into the fruit, and we can make out the structure of the ovary by examining the parts as presented on a larger scale by the fruit, as in the Bean or Sunflower. Quite often, however, changes occur not only in the increased size of the ovary and the hardening or softening of the pericarp, but also in its internal structure. For instance, in the Ash an ovary with two chambers, each containing an ovule, is changed into a one-chambered fruit with one seed; one ovule fails to develop, while the other enlarges, pushing the partition to one side until it joins the wall of the chamber. In Hazel and Oak an ovary with two and three chambers respectively, and two ovules to each chamber, produces in a similar way a one-chambered and one-seeded fruit.

On the other hand, in some cases divisions occur in the fruit which did not exist in the ovary: in Flax a five-chambered ovary becomes a ten-chambered fruit by the folding inwards of the carpels to form new partitions; in Milk-vetch (Astragalus) the one-chambered ovary becomes a two-chambered fruit by the formation of a partition down its whole length; and so on.

The formation of more or less pulpy tissue, as well as the enlargement of parts not belonging to the whorls of the flower, often change the appearance of the fruit, and may make it difficult to trace its development. In the Gooseberry, Grape, Tomato, etc., the seeds lie in pulp formed by the placentas; in the Orange the pulpy matter around the seeds is formed by fleshy cells produced from the inner lining of the fruit-wall; in the Strawberry the receptacle becomes fleshy and bears the ripe carpels on its surface; in the Rose the fleshy hollow receptacle bears the ripe carpels on its concave surface; in the Fig the whole inflorescence becomes fleshy.

159. Pericarp.—The pericarp frequently consists of three layers—an outer layer or *epicarp*, a middle layer or *mesocarp*, and an inner layer or *endocarp*. These layers are easily seen in fruits like Plum or Cherry, where they are distinct from each other: the epicarp is the outer skin, the mesocarp the pulp, the hardened endocarp the stone which surrounds the seed or "kernel." The pulp found in the interior of such fruits as Grape and Gooseberry is formed from the placentas of the ovary, and must not be confused with the mesocarp of Plum and Cherry. In dry fruits the three layers cannot be distinguished, having become blended and having the same texture. In the Date the endocarp is the papery lining around the hard stone or seed; in the Melon the epicarp and endocarp are thin, the mesocarp forming the bulk of the fruit; in the Orange the rind consists of epicarp and mesocarp, while the endocarp forms the partitions filled with pulpy cells. The style or stigma, when remaining in a withered or hardened form at the top of the fruit, serves to distinguish single-seeded fruits from seeds.

160. Simple, Aggregate, and Multiple Fruits.—When a flower produces one fruit, as in Cherry or Oak, the fruit is *simple*. When it produces several similar fruits free from each other, as in Buttercup and Bramble, the fruit is *aggregate*. When several flowers combine to produce one fruit, as in Fig and Mulberry, the fruit is *multiple*. Fruits may be *dry* or *fleshy*; and they may be *dehiscent*, that is, opening to let the seeds escape, or *indehiscent*, remaining closed. Indehiscent dry fruits are in most cases one-seeded; it would obviously be a disadvantage to have numerous seeds germinating close together. Fleshy fruits very rarely open; they are eaten by animals and the seeds thus separated when several are present. Some dry fruits, called *schizocarps* or splitting fruits, break up into one-seeded parts, each part (*mericarp*) as a rule corresponding to one carpel.

161. Opening or Capsular Fruits.—These are divided into three chief kinds.

The *follicle* consists of one carpel, and it opens along the side which bears the seeds (Monkshood, Columbine, Marsh Marigold, Stonecrop, etc.).

The *pod* or *legume* is similar, but opens along both sides (Bean, Pea, and most other Leguminosae).

All dry opening fruits formed from more than one carpel are classed together as *capsules*, though special names are given to each kind. The *siliqua*, characteristic of Cruciferae, opens by two pieces or valves which separate from below upwards, leaving the seeds on the placentas at either edge of the central partition (Fig. 112); the *silicula* is a broad short form of siliqua (Shepherd's-purse, etc.).

Most other capsules split from above downwards. In most

Caryophyllaceae (Stitchwort, Campions, etc.) the splits extend only a short distance downwards, so that the valves form a ring of teeth (Fig. 113), twice as many as the number of carpels (as

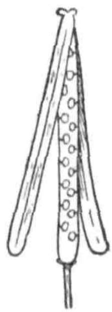


Fig. 112.—FRUIT OF WALLFLOWER.

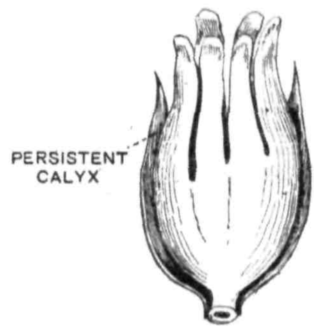


Fig. 113.—CAPSULE OF STITCHWORT OPENING BY SIX TEETH.

indicated by the number of styles on the ovary). When the splits extend from top to bottom, the splitting may occur along the mid-ribs of the carpels (Bluebell, Violet, Iris, etc.), or along the partitions between the ovary chambers (Foxglove, St. John's

Fig. 114.—TRANSVERSE DEHISCENCE OF CAPSULE OF PLANTAIN.

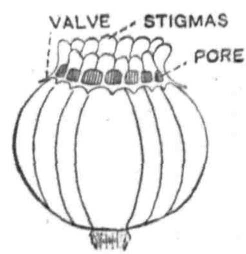


Fig. 115.—CAPSULE OF POPPY. (POROUS DEHISCENCE.)

Wort, etc.). In other capsules the splitting occurs transversely (Fig. 114) so that a lid is cut off (Plantain, Pimpernel, etc.), or pieces of the wall may be cut out so that pores (Fig. 115) are formed (Poppy, Snapdragon, Campanula, etc.).

162. Dry Closed Fruits are given various names, but may here be classed together as *achenes*. An achene behaves like a

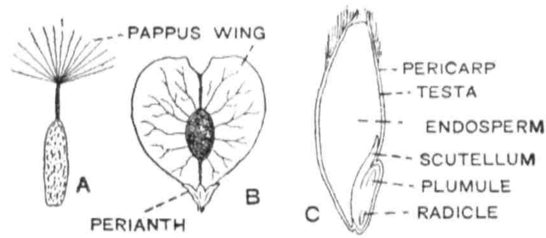


Fig. 116.—ACHENIAL FRUITS.

A, Achene (cypsela) of a Composite; B, Winged achene (samara) of Elm; C, Grain (caryopsis) of Wheat, cut longitudinally.

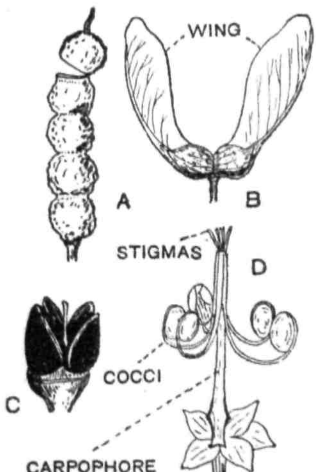


Fig. 117.—SCHIZOCARPS SPLITTING INTO SEVERAL PIECES.

A, Lomentum of Radish; B, Double Samara of Sycamore; C, Nutlets of Dead-nettle; D, Schizocarp of Geranium.

simple seed as regards its dispersal and its germination; the pericarp acts as the protective coat and also bears any appendages present to aid in dispersal, as in the plumed achenes of Clematis, Dandelion (Fig. 116, A), etc., the winged achenes of Elm (Fig. 116, B), Birch, Ash, etc., and the hooked achenes of Avens (Geum), etc. The pericarp usually remains free from the seed-coat, as in the examples just mentioned and in Buttercups, etc., but in the Grasses and Cereals (Gramineae) the two are completely united (Fig. 116, C).

163. Schizocarps or Separating Fruits are so called because they split into two or more one-seeded parts, as in Sycamore (Fig. 117, B), Umbelliferae (Fig. 118), Geranium (Fig. 117, D), the Labiate and Borage families

(Fig. 117, c), Mallow (Fig. 119), etc. In some Leguminosae (Bird's-foot Trefoil, etc.) and some Cruciferae (Radish, etc.) the fruit splits across into one-seeded pieces, and is called a *lomentum* or, more accurately, a lomentaceous pod or siliqua, as the case

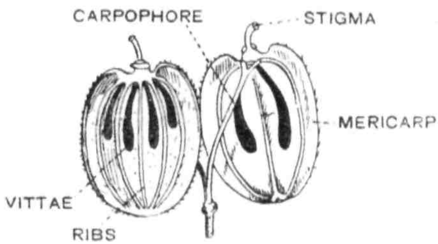


Fig. 118.—SCHIZOCARP OF HERACLEUM (COW PARSNIP).

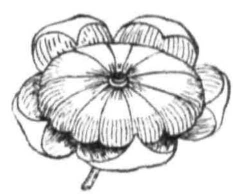


Fig. 119.—SCHIZOCARP OF MALLOW.

may be (Fig. 117, A). The one-seeded parts into which a schizocarp splits do not usually open to let the seed out, but this happens in Spurges and Geranium; such fruits are sometimes called "schizocarp capsules."

164. Fleshy Fruits.—Some more or less fleshy fruits open to let the seeds escape, as in Horse Chestnut, Balsam, Wood Sorrel. Two chief types of closed fleshy fruits can be distinguished. (1) The *berry*, in which the pericarp has no hard part, usually contains several seeds (Gooseberry, Grape, Tomato, etc.), but sometimes only one (Date). (2) The *drupe* is usually formed from a single carpel, the inner layer of the pericarp being fleshy and enclosing the seed, as in Plum, Cherry, Bramble, etc. Drupes may, however, be syncarpous, in which case each chamber of the ovary may form a distinct stone; the fruits of Holly and Elder are compound drupes of this kind.

The difference between a berry and a drupe is simply that the berry contains no hard parts except the seeds, while the drupe has a hard shell or stone (*endocarp*) within which lies the seed, usually without a hard coat. A berry corresponds to a capsule, a drupe to an achene, in which the pericarp has become fleshy instead of dry.

165. Special Types of Fruit.—In giving examples of plants with achenes or drupes some cases have been mentioned where the fruit is aggregate, that is, consists of a number of achenes (Buttercup, Clematis, etc.) or a number of drupes (Bramble, etc.) inserted on a convex receptacle. In the Strawberry the individual fruits are achenes, but the convex receptacle becomes fleshy. In the Rose the fruit is similar but the fleshy receptacle is convex. This leads on to another type of fleshy fruit, the *pome*, as in Apple and Pear, where the fleshy receptacle encloses and is united to the carpels.

In the Mulberry we have a fruit formed from an inflorescence or cluster of flowers; the perianths of the flowers become fleshy and enclose the carpels (Fig. 120, B). The Pine-apple 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; 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 achenes (Fig. 120, A).

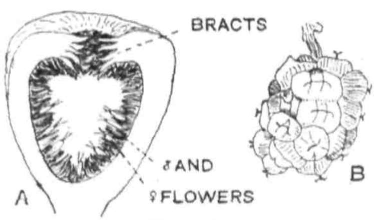


Fig. 120.
A, Fruit of Fig cut in half vertically; B, Fruit of Mulberry.

166. Dispersal of Seeds.—It is clearly impossible that the thousands of seeds which a single plant may produce each year can grow into healthy seedlings on the same area that the adult plant formerly occupied if an annual, or continues to occupy if a perennial. It is therefore important that the seeds should be carried to some distance from the parent plant and from one another, in order to avoid shading and excessive competition in other ways. Apart from occasional methods by which seeds may be carried—that is, methods for which the seeds have no special adaptation, such as violent winds, ocean currents, streams, floating ice, mud on the feet of water-birds, etc. —the regular methods of dispersal are due to four agencies.

These are: wind, water, animals, and explosive mechanisms in the fruit itself.

Dispersal by the *wind* is made more certain and effective either by the small size and weight of the seeds or fruits, or by a flattened shape or the presence of appendages which increase the surface exposed to the wind without adding much to the weight. It is only in the case of dehiscent fruits (capsules) that mechanisms for dispersal are borne by the seeds; closed fruits (achenes) and the segments of splitting fruits (schizocarps) are themselves distributed and have mechanisms for dispersal, while the seeds

Fig. 121.—The Ash, with Cluster of Fruits.

Fig. 122.—The Elm, with Clusters of Fruits.

have none and are carried inside the fruit. The seeds of Orchids are so small and light that when set free they are freely blown about by the wind.

The objects of all adaptations for wind-dispersal are the same, namely, to ensure that the seeds shall become detached from the plant when there is sufficient air movement to do this and to carry them to some distance, while the seed itself is so formed as to fall slowly to the ground, thus increasing the distance to which it is carried. Seeds and one-seeded fruits are often flattened when they are neither very small nor provided with wings or plumes.

Winged seeds are not very common among British plants, but are seen in Pine and Yellow Rattle. Winged achenes are found in Ash (Fig. 121), Elm (Fig. 122), Birch (Fig. 123); in Maple and Sycamore the fruit splits into two winged achenes; in Hop and Hornbeam (Figs. 124, 125) there are persistent bracts which form a wing on the fruit; in the Lime-tree the stalk bearing the cluster of rounded achenes hangs down, and the large bract attached to it acts like a kite; in Docks the fruit is covered by the perianth, 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).

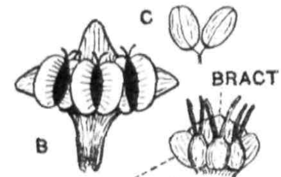


Fig. 123.—Birch.

A, Female flowers in axil of bract; B, Fruiting scale, with three samaras; C, Stamen from male flower.

Fig. 124.—The Hornbeam, with Cluster of Fruits.

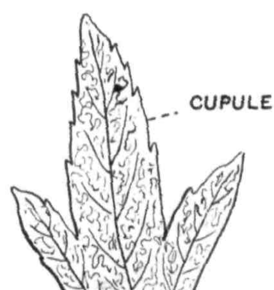


Fig. 125.—Fruit of Hornbeam.

Plumed seeds, in which the appendages are long and hairy instead of scale-like, are seen in Willow, Poplar, Willow-herb, Bog Asphodel, and a few other cases. Plumed achenes are seen in Clematis (persistent hairy style), Cotton-sedge (hairy perianth), Bulrush (hairs on flower-stalk); in Valerians and many Compositae the calyx forms a ring of hairs (pappus) on the top of the achene, and in some Compositae this is carried on a stalk, its efficiency being increased also by each plume being itself feathered, while in moist air the plumes close up into a vertical position, opening out again into a parachute when the air is dry.

Many fruits show what is called a *censer mechanism*, the fruit opening so far as to leave the seeds room to escape, but in such a way that they can only escape when the fruit is shaken to and fro by strong winds. This is seen in follicles and many other capsular fruits, these opening from above downwards so that the seeds can only escape from the top; in Campions, Stitchworts, etc., the teeth bend inwards in damp weather and open out on dry days; in *porous capsules*, as Poppy and Campanula, the exit of the seeds is further limited. In the Labiate and Borage families the achenes (nutlets) lie at the bottom of the persistent cup-like calyx, which acts as a censer. In those Compositae in which the achenes have no pappus the ring of bracts may play the same part, the achenes being loosened and shaken out in strong winds.

Dispersal by *water*, as a regular method, is not common among British plants, and is found chiefly among species growing in water or on the banks of streams. In floating and submerged water plants the fruits are usually ripened under water, and in most cases the seeds when set free simply sink to the bottom or may be carried to some distance by running water. In the Yellow Water-lily the large berry-like fruit breaks off and splits up into separate carpels which float about owing to the air bubbles contained in the slimy pericarp, and as this decays the seeds are set free and sink. In White Water-lily the berry breaks up under water and the mass of seeds floats up to the surface, where the seeds separate; each seed has a spongy aril, enabling it to float about until the air escapes.

In plants which grow on the margin of streams and ponds, or which have their leaves and flowers above the water, the fruits ripen in the air and may either be carried away by wind or may fall into the water; in some cases the seeds have slimy or spongy coats in which air is entangled, so that they can float for a time before sinking or becoming stranded on the mud.

Dispersal by *animals* takes place in various ways. Mud containing seeds may adhere to the feet of birds and thus be carried to considerable distances. But, apart from casual carriage of seeds in this kind of way, there are three regular methods of animal dispersal.

(1) Fleshy fruits are eaten, chiefly by birds, and the seeds pass through the alimentary canal uninjured, being protected by the hard covering. Practically all fleshy fruits are dispersed in this way, the fruit being made attractive by the coloured surface and the sweet fleshy pulp, formed by the pericarp in berries and drupes, by the receptacle in fruits like those of Rose, Strawberry, etc., while the protective covering is either the seed-coat (berries) or the endocarp (drupes) or the whole pericarp.

(2) Many dry fruits have hooks which stick to the coats of passing animals. The fruits are either torn off and carried away adhering to the animal, the hooks being formed either by the style (Avens) or the calyx (Bur-marigold) or as outgrowths of the pericarp or receptacle (Corn Buttercup, Goosegrass, Woodruff, Medick, Sanicle, Chervils, Carrot, Agrimony, Enchanter's Nightshade, etc.), or the bracts are hooked so that a passing animal drags forward the fruit-head and the rebound causes the fruits to be jerked out (Teasel, Burdock).

(3) Some dry fruits or seeds are collected intentionally by animals, which either drop them on the way or carry them to their nests. For instance, acorns and other large fruits are carried away by squirrels and other rodents, which may either let them fall or store them up and not return for them; this is an accidental method of dispersal for which the fruits show no special adaptations.

Much more important is the work done by *ants* in carrying off the small fruits and seeds of many herbaceous plants growing in woods, meadows, and waste places. The seeds and one-seeded fruits carried by ants have food, chiefly of an oily nature, either in an appendage or in the seed-coat or pericarp; this forms the attraction for the ants, and the seeds are either dropped on the way to the nest, or carried into the nest and afterwards carried out again when the oily part has been nibbled off. The oil may be present in a crest or other projection of the seed-coat, as in Bluebell, Greater Celandine, Violet, Gorse, Spurges, Hairy Woodrush, Yellow Fumitory (Corydalis), etc.; or in the substance of the seed-coat itself, as in Garlic; or in the lower part of the pericarp, as in Lesser Celandine, Red Fumitory (Fumaria), etc.; while in various Labiatae and Boraginaceae the nutlets on separating carry away a part of the flower-axis which contains oil.

In some cases the plant has other means of scattering its seeds, but the ants help in carrying them to greater distances; for instance, the seeds of Gorse and Violet are thrown out by explosive action, while in various Compositae with a pappus there is also oil which attracts ants—in Cornflower there are oily swellings at the base of the fruit, in some Thistles the pappus falls off early and the oily body is the base of the style.

167. Explosive or Ejection Mechanisms.—Some fruits show active movements by which the seeds are scattered or thrown out suddenly. These movements often depend upon great turgidity, or swelling, in some part of the fruit, as in the Squirting Cucumber and some Balsams. Almost the only example among British plants is Wood Sorrel, where the capsule opens by a slit down the middle of each chamber, exposing the seeds; each seed has a fleshy cup (aril) at its base, and when ripe the outer part of this cup loses water more rapidly than the inner, setting up tension which results in the cup suddenly turning inside out and shooting the seed away. In most Violets the ripe capsule splits down, midway between the three seed-bearing ridges (placentas), into three boat-shaped valves, and as these dry they contract and squeeze the seeds together, the pressure causing the hard polished seeds to be flicked out to a distance.

The ripe pods of Gorse, Broom, etc., suddenly burst open as they become dried, the two valves becoming twisted and the seeds scattered forcibly. In Crane's-bill (Geranium) the ripe carpels after opening split apart, and from the style there is split off a slender thread attached to each carpel; these threads suddenly curl upwards and outwards, so as to throw out the seeds. In Stork's-bill (Erodium) the fruit is similar, but the thread (awn) on drying twists into a corkscrew form with a free end, while the mericarp has a pointed end and backward-pointing hairs; when it falls on the ground, the free end of the awn catches against the soil, and on becoming moist the awn untwists and lengthens, driving the mericarp into the soil.

168. Practical Work on Fruits and Seeds.—Collect and examine all kinds of fruits, belonging to both wild and cultivated plants, and ascertain their structure and their adaptations for seed dispersal. Make sketches of the fruits and seeds; cut them across or open them up in order to make out the structure. *Distinguish between one-seeded fruits (achenes) and true seeds,* and notice which part of a fruit is fleshy, which part forms wings or plumes, etc. Carefully note and compare the times taken for winged or plumed fruits or seeds to fall to the ground with the wings or plumes still on, and after removing them.

CHAPTER XIV.

SOME FAMILIES (NATURAL ORDERS) OF FLOWERING PLANTS.

169. Classification of Seed Plants.—Seed Plants (Flowering Plants) are divided into two main groups, **Gymnosperms** and **Angiosperms.** In Gymnosperms (Pines, Firs, etc.) 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.

In beginning the study of classification the student should not trouble himself with any particular general scheme, but should simply aim at making himself acquainted with a number of the commoner Families (Natural Orders). This is best done by a careful study and comparison of well-known plants representative of each other.

Only a few Families (Natural Orders) of Angiosperms are dealt with in this chapter. Many others are easily recognised, and the common plants belonging to them should be studied as fully as possible. The plants can be identified by means of a Flora (see Art. 48).

I. DICOTYLEDONS. Embryo with two cotyledons; stem with open bundles, usually in one ring; leaf net-veined; flowers with parts in twos, fours, or fives, rarely in threes.

A. LOWER DICOTYLEDONS. Perianth either absent or in one whorl, or, if in two whorls, the parts of the inner whorl (petals) free.

Natural Orders :—Ranunculaceae, Cruciferae, Leguminosae, Rosaceae, etc.

B. HIGHER DICOTYLEDONS. Perianth in two whorls; corolla, with few exceptions, gamopetalous; stamens twice as many as the petals, or as many, or reduced to 4 or 2, usually epipetalous.

Natural Orders :—Primulaceae, Labiatae, Scrophulariaceae, Compositae, etc.

II. MONOCOTYLEDONS. Embryo with one cotyledon; stem with closed bundles, "scattered" in cross-section; leaves generally parallel-veined; flowers with parts in threes.

Natural Orders :—Liliaceae, Amaryllidaceae, Iridaceae, Orchidaceae, Gramineae, etc.

170. 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 (Art.

46). The corolla is called *papilionaceous* ("butterfly-like"); the flower is slightly perigynous; stamens 10, monadelphous or diadelphous; pistil of one carpel; fruit a pod or a "lomentum," or (in some Clovers) an achene. Most of the flowers are adapted for cross-pollination by bees; but some of the larger flowers may be visited by butterflies and moths, and the smaller flowers by shorter-tongued insects. Honey, when present, is secreted inside the base of the stamen-tube; in this case the posterior stamen is free (diadelphous condition). In flowers with monadelphous stamens there is no honey.

The lateral petals are jointed to the keel, so that when the insect alights on the lateral petals the keel also is depressed and the style and stamens may protrude or escape from the keel. The mechanism differs in different cases. In the Clovers the stamens and stigma simply protrude, and return inside the keel when the insect flies away. In Vetches and Peas the style has a tuft of hairs serving as a piston to brush out the pollen which has collected in the keel. In Bird's-foot Trefoil the keel petals are joined above as well as below, leaving only a small opening at the tip, and the pollen is brushed out by the five long stamens, which are thickened below the anthers. In the Gorse and Broom the flower explodes; the stamens and style are tightly held in the keel under tension and spring out violently when the keel is depressed.

The British Papilionaceae may be divided into five tribes according to the characters of the leaves, etc. :—

1. *Gorse Tribe.*—Leaf simple or of 2 or 3 leaflets, no tendrils, leaf or leaflets with entire margin. The calyx is deeply two-lipped and coloured in Ulex; shortly two-lipped and green in Genista (each lip deeply toothed) and Cytisus (each lip minutely toothed). Ulex (**Gorse**) has simple narrow flat pointed leaves and green grooved branches ending in a spine. Genista anglica (**Needle Gorse**), on heaths, has very small simple leaves and slender curved spines; G. tinctoria (**Dyer's Greenwood**), in meadows, has no spines, and its leaves are larger. Cytisus scoparius (**Broom**), on heaths, has leaves with usually 3 leaflets, no spines, numerous angular green branches.

2. *Clover Tribe.*—Like Gorse tribe, but with serrate leaflets. Ononis has monadelphous stamens; in Trifolium the flowers are in heads and the pod is straight, in Medicago the flowers are in

racemes and the pod is coiled. Ononis (**Rest-harrow**) usually has spines; the leaves have usually 3 leaflets; the pink flowers are single or in short racemes. Trifolium (**Clovers**) have very characteristic leaves with 3 obovate leaflets which show sleep-movements; T. repens (**White** or **Dutch Clover**) has runners; T. pratense (**Red Clover**) has no runners; there are several other common species (see Flora). Medicago (**Medicks**) has leaves and flowers rather like those of Clover; M. lupulina (**Black Medick**) has small yellow flowers and small black smooth kidney-shaped one-seeded pods. M. maculata (**Spotted Medick**) has larger leaflets, flowers and pods, the leaflet usually has a dark central spot, and the many-seeded pod has 3 to 5 coils and bears curved spines.

3. *Lotus Tribe.*—Leaf with 2 or more pairs of leaflets and an end leaflet, no tendrils. The calyx is shorter than the corolla in Lotus (pod constricted between the seeds) and Astragalus (pod divided by a longitudinal partition), longer than the corolla in Anthyllis. Lotus corniculatus (**Bird's-foot Trefoil**) has 5 leaflets, the 2 lowest being close to the stem and looking like stipules (the real stipules are very small). Astragalus (**Milk Vetch**) has 10 to 12 pairs of leaflets, flowers purple or cream-white in racemes or spikes. Anthyllis (**Lady's Fingers**) has 2 to 6 pairs of leaflets and is covered with silky hairs, especially the flower-heads, which are in pairs, flowers yellow.

4. *Sainfoin Tribe.*—Like Lotus tribe, but pod consisting of one or more indehiscent one-seeded joints. Ornithopus (**Bird's-foot**) has 6 to 12 pairs of leaflets, white flowers, and curved jointed cylindrical pods breaking across into one-seeded parts. Hippocrepis (**Horse-shoe Vetch**) has flowers like Lotus but smaller, 4 to 6 pairs of leaflets, and a curved flat pod breaking into horse-shoe-like joints.

5. *Vetch Tribe.*—Leaf ending in a tendril or point. In Lathyrus (**Peas, Vetchlings**) the leaflets are few, often 1 or 2 pairs; in Vicia (**Vetches**) there are usually at least 6 pairs. Several species of both genera are common: see Flora.

171. The Buttercup Family (**Ranunculaceae**) is distinguished by the complete absence of cohesion or adhesion between the parts of the flower. The flower is hypogynous, and 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 fruits are usually either follicles or achenes. 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.

The flowers are usually protandrous, with the anthers extrorse (opening on their outer faces), but those of Thalictrum, Helleborus, and Eranthis are protogynous, and those of Wood Anemone and Trollius are homogamous. 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 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.

Wood Anemone and Traveller's Joy are honeyless flowers, visited chiefly by small insects (flies, etc.) for pollen, but in some species of Anemone and Clematis there are honeyed staminodes partially concealed by the sepal-bases and the stamens, and therefore only reached by fairly long-tongued insects. Adonis and Thalictrum are also "pollen flowers"; some species of Thalictrum are largely wind-pollinated, though the kinds with coloured anthers are visited by insects.

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 (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, Monkshood (Fig. 81), and Larkspur (Fig. 82) 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."

The only really common genera of Ranunculaceae in Britain are Ranunculus, Anemone, Clematis, and Caltha, but many are cultivated in gardens for their showy flowers. Excepting Actaea (berry) and Nigella (capsule) the family falls into two well-marked divisions according to whether the fruits are achenes or follicles.

I. *Fruit a collection of achenes.*—A. Shrubs with opposite leaves—Clematis. B. Herbs with alternate leaves. 1. Sepals petaloid, no petals. (*a*) A ring of bracts below the flower—Anemone. (*b*) No bracts—Thalictrum. 2. Sepals and petals present—Ranunculus.

II. *Fruit a collection of follicles.*—A. Flower regular. 1. Sepals persist in fruit—Helleborus. 2. Sepals fall off. (*a*) Petals absent—Caltha. (*b*) Petals small, entire—Trollius. (*c*) Petals small, two-lipped—Eranthis. (*d*) Petals large, spurred—Aquilegia. B. Flower zygomorphic. 1. Uppermost sepal hooded—Aconitum. 2. Uppermost sepal spurred—Delphinium.

Clematis (**Traveller's Joy, Old Man's Beard**), in hedges, climbs by its petioles, which are sensitive on the lower side and after turning round a support turn woody and persist; leaves of *3 or 5 leaflets*; *flowers* with 4 greenish-white sepals and numerous stamens and carpels, achene with a long plume (persistent style). Many species of Clematis are cultivated, some with large brightly coloured flowers. **Wood Anemone** (Anemone nemorosa), very common, has a thin rhizome giving off long-stalked leaves with 3-lobed leaflets, and solitary long-stalked flowers with a ring (involucre) of 3 leaves (bracts) below the flower, which has 6 (5 to 9) white or pink sepals and numerous stamens and carpels. In **Pasque Flower** (A. pulsatilla), on limestone downs, the flowers are purple and tubular, with honeyed staminodes within the sepals, the style becomes long and feathery (as in Clematis), and the 3 bracts are many-lobed. In the "Hepatica" Anemone the usually blue flowers have 3 undivided bracts just below the sepals, and therefore resembling a calyx. Examine also the many-coloured Poppy-like Anemones and the white Japanese Anemone of gardens. **Meadow Rue** (Thalictrum) has compound leaves, often like Maiden-hair Fern, flowers in crowded inflorescences, small, with 4 or 5 small sepals, which soon fall off, yellow or green in the 3 British species, but with pink anthers in some cultivated forms; stamens erect, forming the conspicuous part of the flower, carpels few. **Ranunculus** (Figs. 54, 76) includes the Buttercups (Crowfoots) and Spearworts. Typical floral formula K5 C5 A∞ A∞. R. ficaria, the **Lesser Celandine,** has 3 sepals and 8 petals. R. acris is the **Meadow Buttercup.** In R. bulbosus, the **Bulbous Buttercup,** the stem is swollen at the base, and the sepals are reflexed. R. repens, the **Creeping Buttercup,** has runners which root at the nodes. R. sceleratus, the **Celery-leaved Buttercup,** is an annual growing in ditches; there is no scale to the nectary at the base of the petal. The **Corn Buttercup,** R. arvensis, is a troublesome cornfield weed with large achenes covered with hooked spines.

The **Water Crowfoots** are very variable. They have white flowers. The commonest form has the lower leaves submerged and finely cut, and the upper ones floating, with broad lobes. (See Art. 106.)

The Spearworts are easily distinguished from the ordinary Buttercups or Crowfoots by their long narrow leaves. They grow in marshy places. R. flammula is the **Lesser Spearwort;** R. lingua, the **Greater Spearwort.**

For **Helleborus** examine a cultivated "Christmas Rose" or "Lenten Rose," noting the rhizome, often black, which gives off aerial shoots ending usually in a single flower or bearing a few flowers, and giving off (below surface of soil) the stalked compound leaves; the flower is inclined on its stalk, and consists of 5 or 6 large sepals (white or pink with green base, persisting and turning green in fruit), 13 (range 10 to 21) stalked green 2-lipped slipper-shaped nectaries, numerous stamens, 5 (sometimes 6 to 10) carpels more or less joined at base.

There are two wild **Hellebores** in Britain on limestone in South and East England—the Setterwort (H. foetidus, perennial, aerial stems with numerous drooping flowers, sepals green edged with brown and not spreading until nectaries and stamens have fallen) and Bearsfoot (H. viridis, annual, flowers few, inclined, sepals spreading); both have 3 carpels.

Winter Aconite (Eranthis) has a tuberous rhizome, "radical" leaves, each with a circle of 3 to 5 lobed leaflets; flowers solitary, with an involucre of 2 or 3 lobed leaves, 5 to 9 yellow sepals which close up at night and in bad weather, 5 to 9 tubular nectaries alternate with sepals, about 30 stamens, 3 to 11 carpels.

Globe Flower (Trollius), rare wild (on hills), but often cultivated, has globular yellow flowers, with 5 to 15 petaloid sepals, 5 to 15 smaller petals, with nectary pit at base, numerous short stamens, 5 or more carpels.

Paeony. Note the tuberous roots and the large flowers which close at night; sepals 5, passing gradually outwards into the foliage-leaves, 5 or more petals without nectaries, numerous stamens, and few (often 2 or 3) large fleshy carpels, joined at base; honey produced abundantly by a disc around the carpels; in some species the flower has a tubular disc.

Examine the **Columbine** (Aquilegia), often cultivated in many species and varieties with variously coloured flowers; A. vulgaris, chiefly on limestone, has deep blue flowers (May-July) 1 to 2 in. across, drooping (but erect in fruit), 5 petaloid sepals, 5 petals with long basal honey-spurs hooked at end, many stamens, 5 or more carpels.

Monkshood (Aconitum), not common in Britain, but much cultivated in gardens; flowers blue, with 5 petaloid sepals, the uppermost one forming a large hood, the lowest pair small; petals represented by 2 long-stalked curious nectaries under the sepal-hood, the other 3 small or absent; filaments of stamens broad at base; carpels 3 to 5. (See Fig. 81.)

Larkspur (Delphinium) is also chiefly known by the garden forms; flowers blue, etc., with 5 petaloid sepals, the uppermost having a long basal spur; 2 upper petals, small, each with a spur, the two spurs projecting into the sepal-spur and being pressed together so as to form a tube above and a solid mass (nectary) below; the lowest petal is usually absent, but the other two (also absent in D. ajacis) are brightly coloured and hairy, standing at each side of the entrance to the sepal-spur; carpels 3 to 5, often reduced to 1. (See Fig. 82.)

172. The Wallflower Family (Cruciferae) is easily distinguished by the following characters of the flower—polypetalous, hypogynous, corolla of four petals arranged like a cross, stamens tetradynamous (two short, four long), ovary two-chambered and with parietal placentas, fruit a siliqua or silicula (sometimes a lomentum). The plants are herbaceous, though in some cases more or less shrubby; the leaves are alternate and have no stipules. Familiar examples are Wallflower (Fig. 83) and Shepherd's Purse. The inflorescence is usually a raceme or corymb, without bracts. The symmetry of the flower is bilateral (see Fig. 126). The two lateral sepals are pouched at the base; the petals usually show a narrow lower part (claw or stalk) and a broad upper part (limb), the claw being erect and the limb spreading. The two short lateral stamens form an outer whorl; the four long inner stamens are in two pairs (anterior and posterior). The nectaries are small green glands on the receptacle at the bases of the short stamens; the honey gathers in the pouches of the lateral sepals.

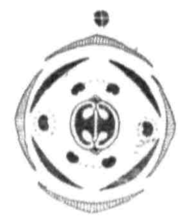


Fig. 126.—FLORAL DIAGRAM OF A CRUCIFER.

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 to 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 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.

173. The Rose Family (Rosaceae) is distinguished by the following characters of the flower: regular, perigynous, gamosepalous, polypetalous, stamens numerous, carpels free and usually also numerous. At first sight some of the Rosaceae, especially the Potentillas, look like Buttercups, but they are easily distinguished by having the flower perigynous and the sepals joined.

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 (Fig. 92). 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 (achenes, drupes, drupelets, follicles, and pomes) found in this family is due to various causes—persistence or non-persistence of receptacle ("calyx-tube"), dryness or fleshiness of pericarp or receptacle, number and form of ripe carpels, etc.

The flowers are insect-pollinated (except Poterium) and 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. 92) 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, Pear, 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 sometimes homogamous (Common Cherry, Gean, Dropwort, etc.) or protandrous (Roses, Potentillas, Meadowsweet, etc.). Self-pollination is apparently possible in all cases.

The chief genera of Rosaceae may be distinguished by the following key:—

I. Ripe carpels not enclosed in receptacle. A. Calyx falls off after flowering, 1 carpel, fruit a drupe—Prunus. B. Calyx persists after flowering. 1. No epicalyx. (*a*) Carpels 5 to 12, fruits dry—Spiraea. (*b*) Carpels numerous, fruit of small drupes (drupels)—Rubus. 2. Epicalyx present. (*a*) Style lengthens and becomes hooked—Geum. (*b*) Style does not elongate. (i) Receptacle becomes fleshy—Fragaria. (ii) Receptacle remains dry—Potentilla.

II. Ripe carpels enclosed in receptacle. A. Receptacle dry in fruit. 1. Petals present—Agrimonia. 2. Petals absent. (*a*) Epicalyx present, leaves palmate—Alchemilla. (*b*) Epicalyx absent, leaves pinnate—Poterium. B. Receptacle fleshy in fruit. 1. Carpels many—Rosa. 2. Carpels 5 or fewer. (*a*) Carpels stony, one-seeded—Crataegus. (*b*) Carpels leathery, usually two-seeded—Pyrus.

Prunus has many species, both wild (see Flora) and cultivated, including the **Sloe** or **Blackthorn, Cherry, Plum,** etc., and is characterised by the single carpel and the falling off of the receptacle after flowering. Spiraea includes S. ulmaria (**Meadowsweet**), in damp places, with leaves downy below, small flowers in dense flat-topped inflorescences, carpels twisted and horizontal; and S. filipendula (**Dropwort**), in dry places, leaves not downy below, smaller, carpels straight and erect. Rubus includes the **Brambles** or **Blackberries** and the **Raspberry,** with numerous carpels on central knob-like portion of receptacle, the carpels becoming fleshy (drupes). Geum has 2 British species, both erect perennials with numerous pinnate "radical" leaves (compound with numerous paired side leaflets and a much larger end leaflet), achenes with a hooked style for animal dispersal; G. urbanum (**Avens**) has erect yellow flowers and grows in hedgerows, etc.; G. rivale (**Water Avens**), beside streams, has larger drooping flowers with red-brown calyx-lobes and orange petals. Fragaria is the **Strawberry.** Potentilla is very similar to Fragaria, but the receptacle does not become fleshy; most of the species have yellow flowers, but P. fragariastrum (**Barren Strawberry**) has white flowers like the Strawberry. P. tormentilla (**Tormentil**), on heaths, has small flowers with 4 petals. The other species have 5 petals—P. reptans (**Creeping Cinquefoil**), in hedges, has creeping stems and its leaf has 5 leaflets; P. anserina (**Silverweed**), on road-sides, sand, etc., has long runners, very numerous leaflets, and larger flowers.

Agrimonia (**Agrimony**), in hedges, etc., has pinnate leaves with 3 to 10 pairs of leaflets, and a long raceme of small yellow flowers; the receptacle is top-shaped and covered with hooked spines, and contains 2 carpels; after flowering the stalk bends down and the hooked receptacle helps in animal dispersal. Alchemilla vulgaris (**Lady's Mantle**) has rounded 6- to 9-lobed palmate leaves, small yellowish-green flowers in flat-topped inflorescences, K-lobes 4, with 4 bracts (epicalyx), no petals, 4 stamens on mouth of receptacle which is nearly closed by a honey-disc but allows the styles of the 2 (sometimes only 1) carpels to project; A. arvensis (**Parsley Piert**) is a smaller plant, annual, leaves fan-shaped and 3-lobed, flowers very small, stamens only 1 or 2. Poterium sanguisorba (**Salad Burnet**), on chalk downs, has small flowers in clusters with female flowers above and male below, the females opening first and having usually 1 carpel with a much-branched stigma, males with numerous stamens hanging out loosely, K-lobes 4, no petals; P. officinale (**Great Burnet**), in most pastures, etc., has hermaphrodite flowers in an oblong head, only 4 stamens. Rosa (**Roses**) has many British species, characterised by the prickly stems, pinnate leaves, and the deep urn-like receptacle which contains the numerous carpels and becomes fleshy ("hip"). Crataegus (**Hawthorn**) has stem-spines, lobed but simple leaves, and flat-topped clusters of flowers resembling those of Rose in general structure, but with only 1 or 2 carpels which become hard and stony in fruit. Pyrus includes the **Rowan, White Beam, Wild Service, Apple, Pear,** etc., characterised by the pome fruit.

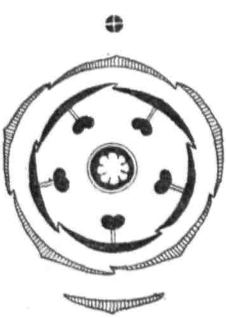


Fig. 127.—FLORAL DIAGRAM OF PRIMROSE.

174. 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 (Fig. 127).

The flowers are usually homogamous and honeyed. Heterostyled dimorphic flowers occur in many species of Primula (Fig. 104), also in Yellow Loosestrife and Glaux (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 anthers open inwards in Primulaceae). The long-tubed forms are largely visited by bees and butterflies; the honey is secreted by a ring round the base of the ovary.

In Primrose and Cowslip 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.

The commoner British genera of Primulaceae are Primula (leaves all "radical"), Lysimachia (leaves on the aerial stems, capsule opening by teeth), Anagallis (capsule opening by a lid), and Glaux (no corolla). Primula is represented chiefly by P. vulgaris (**Primrose**), with the flowers on separate stalks arising from the rhizome, and P. veris (**Cowslip**), with the flowers in an umbel. Lysimachia has 2 common British species: L. vulgaris (**Yellow Loosestrife**), beside streams, with stems 2 to 4 feet high, sessile opposite leaves, flowers in clustered cymes; L. nummularia (**Moneywort** or **Creeping Jenny**), with flowers single in the axils of the rounded leaves. Anagallis arvensis (**Scarlet Pimpernel**), in fields, etc., has 4-angled stem, sessile decussate ovate leaves, flowers solitary in leaf-axils with short-tubed star-like corolla; A. tenella (**Bog Pimpernel**) is perennial, with pink funnel-shaped corolla.

175. 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

Fig. 128.—Dead-nettle, showing two Clusters of Flowers.

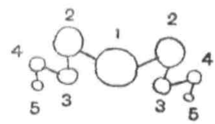


Fig. 129.

Diagram indicating the relation of Flowers in half of a cluster ("Verticilfaster"). The numbers indicate the order in which the flowers open.

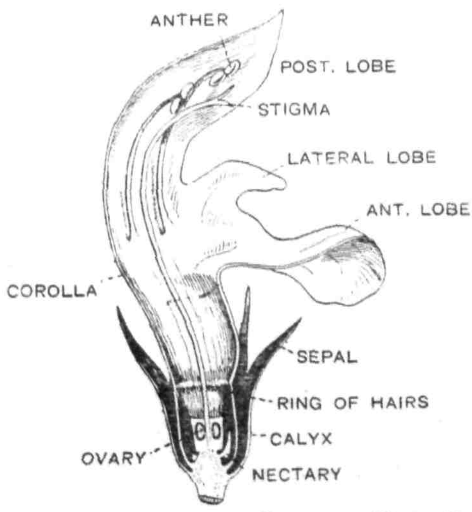


Fig. 130.—Longitudinal Section of Flower of White Dead-nettle.

with four one-seeded chambers. By the structure of the ovary and the fruit of four achenes (Fig. 117, c) Labiates are distinguished from those plants of the Foxglove Family which have square stems, decussate leaves, and bilabiate flowers with two pairs of stamens (see Figs. 128-131).

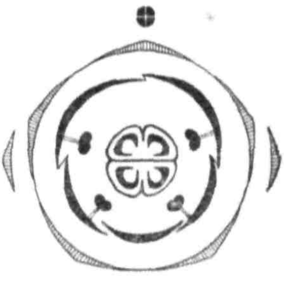


Fig. 131.—FLORAL DIAGRAM OF LABIATAE.

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.

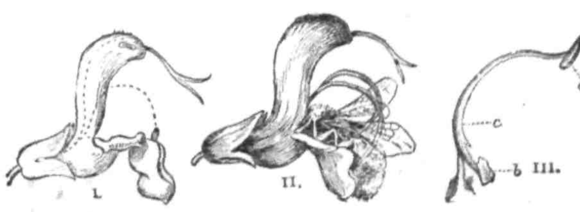


Fig. 132.

I., Flower of sage from side ; II., With Humble-bee extracting Nectar, and the Anthers rubbing against his back ; III., Single Stamen.

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) only two stamens are present, and 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) the lower end of the connective is barren and flattened and the upper part of the connective is longer than the lower, the whole forming a delicate lever. A bee on entering the flower (Fig. 132) pushes against the united lower ends (*b*) 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. In an older flower the style bends down and the stigma is touched first by a bee entering the flower.

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.

The Labiatae are well represented in Britain. A Flora should be consulted for details as to species, but the following key may be of assistance.

I. Ovary chambers separate to the very base. A. Stamens 2, with long connectives—Salvia (**Sage**). B. Stamens 4, the upper pair longer—Nepeta (**Ground Ivy**). C. Stamens 4, the lower pair longer.

1. Stamens spread out and project from C-tube. (*a*) Corolla regular or nearly so. (i) Flower with 4 perfect stamens—Mentha (**Mint**). (ii) Flower with 2 perfect stamens—Lycopus (**Gipsy-wort**). (*b*) Corolla 2-lipped. (i) Plant tall, erect; K 5-toothed —Origanum (**Marjoram**). (ii) Plant low, creeping; K 2-lipped—Thymus (**Thyme**). 2. Stamens (4) come together below upper C-lip; K-tube with 13 ribs—Calamintha (**Calamint**). 3. Stamens (4) parallel or nearly so; K-tube with 5 or 10 ribs or veins. (*a*) K tubular, C-tube short—Marrubium (**White Horehound**). (*b*) K 2-lipped, closing over fruit. (i) Upper K-lip flat; filaments forked—Prunella (**Self-heal**). (ii) Upper K-lip pouched; filaments simple—Scutellaria (**Skull-cap**). (*c*) K 5-toothed, funnel-shaped, teeth generally spreading. (i) Anthers hairy (exc. Yellow Dead-nettle). (*α*) Nutlets with flat top—Lamium (**Dead-nettle**). (*β*) Nutlets with round top —Galeopsis (**Hemp-nettle**). (ii) Anthers not hairy. (*α*) K-

teeth broad and blunt—Ballota (**Black Horehound**). (β) K-teeth narrow and sharp—Stachys (**Woundwort**).

II. Ovary chambers joined at least half-way up. A. Upper C-lip entire or slightly notched—Ajuga (**Bugle**). B. Upper C-lip deeply cleft—Teucrium (**Wood Sage**).

176. The Foxglove Family (Scrophulariaceae) shows a fairly wide range of flower structure, as seen from a study of Foxglove and Speedwell, but all agree in having the flower zygomorphic (in some cases nearly regular), with gamosepalous calyx (sometimes almost polysepalous), a gamosepalous and

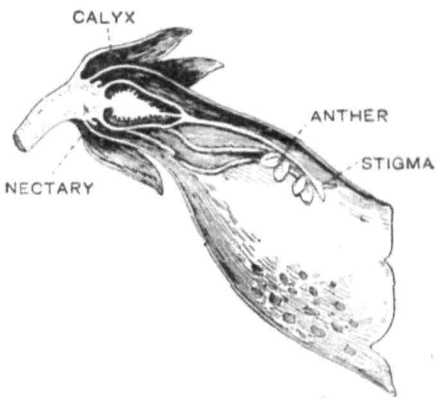


Fig. 133.—LONGITUDINAL SECTION OF FLOWER OF FOXGLOVE.

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. (See Figs. 133, 134.)

The flowers of most Scrophulariaceae are adapted for pollination by bees. 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 stigma has two flat lobes, and when it is touched on the inner surface the lobes close, so that any pollen deposited by a bee in entering the flower is securely held, while the bee in leaving the flower cannot place on the stigma pollen from the flower's own stamens.

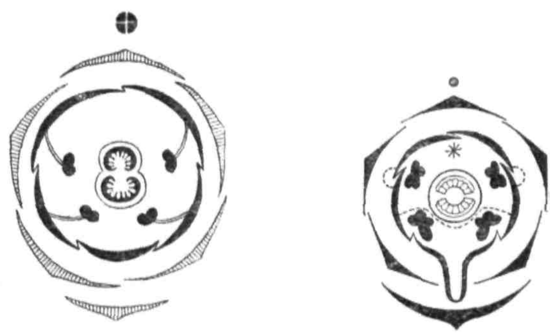


Fig. 134.—FLORAL DIAGRAMS OF FOXGLOVE (LEFT) AND OF TOADFLAX (RIGHT).

The open short-tubed flowers of Verbascum can be visited by all kinds of insects. Those of Veronica (Speedwell) are placed vertically and appear to be specially adapted for the visits of hover-flies. 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 underside 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.

Figwort (Scrophularia), which is largely visited by wasps, is *protogynous.* In the newly opened flower (Fig. 103) 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 style withers and falls on the front of the corolla, the visiting insect rubs the stigma and anthers with its underside 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, Pedicularis, Bartsia, Melampyrum, and Euphrasia 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 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.

The British Scrophulariaceae are fairly easy to distinguish. The genus Veronica (Speedwell) is largely represented, and reference should be made to a Flora for its species, but the genus is known by its usually blue flowers, with 4 sepals, 4 petals (the uppermost usually larger than the rest), and 2 stamens. Verbascum (**Mullein**) has regular 5-lobed corolla and 5 stamens. Linaria has the corolla-tube spurred at the base; L. vulgaris (**Toadflax**) has yellow flowers in a raceme; L. cymbalaria (**Ivy-leaved Toadflax**) has axillary long-stalked lilac flowers, and after pollination the flower-stalk turns from the light and forces the capsule into dark crannies in the walls on which the plant usually grows. In Antirrhinum (**Snapdragon**) the corolla has a blunt pouch instead of a spur; the capsule opens by 3 pores at the top. Scrophularia (**Figwort**) has 4-sided stem, decussate leaves, and dull purplish flowers in axillary cymes; the posterior stamen is represented by a scale or staminode (Fig. 103).

Digitalis (**Foxglove**) has large flowers with open glove-finger-shaped corolla (Fig. 133). All the remaining British genera are semi-parasitic plants, their roots being attached to the roots of other plants, chiefly grasses; and they are also distinguished by having the 2 upper corolla lobes, which form a hood, covered in the bud by one or both of the lateral lobes. Pedicularis has pinnate leaves and red flowers with 5-lobed calyx; P. sylvatica (**Lousewort**), in damp fields, is perennial; P. palustris (**Red Rattle**), in marshes, is annual. In the other semi-parasitic genera the calyx is 4-lobed and the leaves simple and decussate: Rhinanthus (**Yellow Rattle**) has yellow flowers, calyx inflated, seeds winged; Melampyrum (**Cow-wheat**) has long pale yellow flowers, calyx not inflated; Bartsia has purplish-red flowers; Euphrasia (**Eyebright**) has white flowers with purple veins and yellow lower lip.

177. The Composite Family (**Compositae**) is the largest among flowering plants. 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 1,300 species of one genus (Senecio) alone.

The general structure of the flower is remarkably uniform throughout this huge family. In all cases the head is surrounded by an envelope (involucre) of bracts (Fig. 100), 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 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 achenes.

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 (Fig. 116, A). 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 at the same time 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. 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 (Fig. 135). 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.

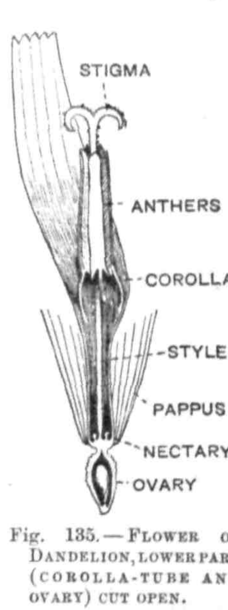


Fig. 135.—Flower of Dandelion, lower part (corolla-tube and ovary) cut open.

The Composites are practically all insect-pollinated, and have a beautiful and effective mechanism of a comparatively simple type. 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.

The grouping of the small flowers into heads—an arrangement not peculiar to Composites, but found in many other 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, racemes, etc.).

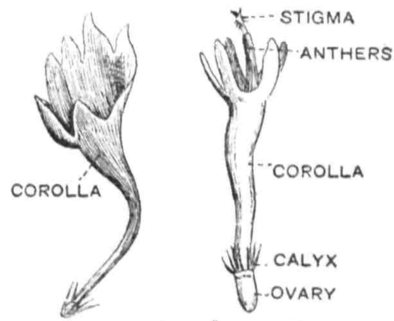


Fig. 136.—CORNFLOWER (CENTAUREA).
Outer neuter flower on left. Tubular hermaphrodite flower on right.

The most striking arrangement is that in which the outer flowers, forming the ray, differ from the inner ones in having ligulate corollas or larger tabular corollas (Cornflower). In such cases the outer flowers are generally female and the inner ones hermaphrodite; this is probably due simply to the extra material for the large corolla of ray-flowers being supplied at the expense of the stamens, and these flowers are in many species rarely fertilised—in some cases they are completely sterile, having no style or ovule as in Cornflower (Fig. 136).

Cross-pollination is made inevitable in a few cases, owing to the flowers being unisexual, the male flower having an empty ovary and a style which acts only as a pollen-piston. In some such plants the head contains only male or female flowers, and the male and female heads are on separate plants, *e.g.* Saw-wort, Creeping Thistle, Butterbur. Even when all or most of the flowers are hermaphrodite, the flowers open successively towards the centre of the head, so that pollen will usually be brought by insects from another head; failing that, self-pollination nearly always occurs eventually owing to the curling back of the stigmas.

The mechanism of the essential parts is practically uniform in the whole family. In most cases the corolla-tube is short enough to allow all except the shortest-tongued insects to reach the honey secreted by the ring-like nectary at base of style. The depth of the tube varies considerably, but in most cases the lower part of the tube is so narrow that the honey rises in it and can be sipped by long-tongued flies and short-tongued bees; the longest-tubed forms (Centaurea, Thistles, etc.) are chiefly visited by butterflies and the long-tongued bees, the shortest-tubed forms (*e.g.* Milfoil, Daisy) by flies.

The British species of Compositae are too numerous to be noted here; reference should be made to a Flora. In the following lists the more important forms are mentioned.

I. All the flowers ligulate. Flowers yellow (except in Chicory); pappus present except in Lapsana.

Taraxacum dens-leonis is the **Dandelion.** There are five common species of Hawkweed (Hieracium) with many varieties; the commonest is H. pilosella, the **Mouse-ear Hawkweed.** Crepis virens (**Smooth Hawk's-beard**) is an annual very common in cultivated and waste ground. Sonchus (**Sow-thistle**) has 3 common species, all with hollow stems and jagged stem-clasping leaves—S. arvensis, perennial, chiefly in corn-fields, and S. oleracea and S. asper, annuals, in cultivated and waste places. The common species of Lactuca is L. muralis, the **Wall Lettuce. Cat's-ear** (Hypochoeris radicata) is very common in meadows and sandy places. Tragapogon pratensis is the **Goat's-beard;** T. porrifolius, **Salsify**, with purple flowers, occurs as a garden-escape in the south of England. **Chicory** (Cichorium intybus), in England, by roadsides and in fields, has blue flowers and scaly pappus. Lapsana communis is the **Nipplewort.**

II. All the flowers tubular. **Bur Marigold** (Bidens cernua) and **Hemp Agrimony** (Eupatorium cannabinum) occur in damp places. Artemisia vulgaris is the **Mugwort;** A. absinthium, **Wormwood.** The genera Gnaphalium, Filago, and Antennaria include the **Cudweeds;** Gnaphalium uliginosum, the **Marsh Cudweed,** is common in wet places; Antennaria dioica, the **Mountain Everlasting,** is dioecious. The **Burdock** (Arctium Lappa) is common on roadsides; it has large cordate leaves, and the involucral bracts have hooked tips. In Carlina vulgaris, the **Carline Thistle,** the leaves have spiny teeth, and there are bristles between the florets.

Carduus includes the true Thistles; the three commonest species are C. arvensis (**Creeping Thistle**), with male and female flowers in separate heads on different shoots, C. lanceolatus (**Spear Plume Thistle**), and C. palustris (**Marsh Plume Thistle**). Onopordon acanthium, the **Cotton** or **Scotch Thistle,** differs from the true Thistles in having no bristles between the flowers. The commonest species of Centaurea is C. nigra (**Hardheads,** Knapweed), in which the bracts of the involucre overlap, and have a broad, black, fringed margin; either with or without larger, neuter outer flowers. C. scabiosa is the **Greater Knapweed,** with a ray of neuter flowers, and broader bracts with narrow fringe. C. cyanus, the **Bluebottle** or **Cornflower,** in cornfields, has very large blue neuter flowers and is often cultivated.

III. Outer (ray) flowers ligulate, inner (disc) flowers tubular. Tanacetum vulgare, the **Tansy,** has large pinnate leaves; outer flowers female, with short ligule; inner flowers male; common but not native in Britain. Achillea has two common British species—A. millefolium (**Milfoil** or **Yarrow**) and A. ptarmica (**Sneezewort**). The two common species of Chrysanthemum are C. leucanthemum (**Ox-eye Daisy**) and C. segetum (**Corn Marigold**). In Anthemis cotula (**Stinking Mayweed**) the leaves are twice pinnate, and the ray flowers neuter; A. arvensis is the **Corn Chamomile.** There are two species of Matricaria —M. inodora (**Scentless Mayweed**) and M. chamomilla (**Wild Chamomile**). Aster tripolium, the **Sea Aster,** is found in salt marshes; it has narrow fleshy leaves, and flowers resembling those of the Michaelmas Daisy.

Senecio is the largest genus of Flowering Plants, having over

1200 species (only 9 in Britain). The common British species are S. vulgaris, the **Groundsel**, which has no ligulate ray flowers and is mostly self-pollinated; S. jacobaea, the **Ragwort**; and S. aquatica, the **Marsh Ragwort.** Inula crithmoides, the **Golden Samphire,** grows in salt marshes; I. dysenterica is the **Yellow Fleabane. Golden Rod** (Solidago virgaurea), with *small bright yellow heads of flowers, is found in moist woods.*

178. 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. In Bluebell and Tulip the perianth-parts are free from each other, whilst in the majority of Liliaceae (Fig. 77) 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.

The fruit is either a capsule or a berry.

The British Liliaceae may be roughly divided into (1) bulbous plants, (2) rhizomatous plants.

Of British Liliaceae with bulbs, Allium (**Garlic**) has flowers in umbels or heads (enclosed at first in a scaly 2-leaved involucre) on long flowering stems; A. ursinum (**Ramsons**) is common in woods. The others have flowers in racemes; Fritillaria (**Snake's-head,** flowers large, drooping, P.-leaves free, purple with square whitish dots), Tulipa sylvestris (**Wild Tulip,** flower yellow, erect, P.-leaves free recurved), and Gagea (**Yellow Star of Bethlehem,** P.-leaves free spreading, flower small), all rare in Britain, have leaves on the following stem. The leaves are all "radical" in Scilla (2 rare species in Britain besides the common Bluebell), Ornithogalum (**Star of Bethlehem,** flowers white, P.-leaves free spreading), and Colchicum (**Meadow Saffron,** flowers lilac, P.-tube very long).

Solomon's Seal (Polygonatum multiflorum), in woods, has a thick rhizome (Fig. 62), sending up each year a leafy shoot; leaves alternate, ovate, all turning to one side; flowers 2 to 8 in leaf-axils, drooping on lower side of shoot, P.-tube bell-like, white, berry bluish-black. The leaves are all "radical" in **Lily of the Valley** (Convallaria, in woods, not common, flowers in a raceme, white, drooping, P. bell-like with recurved lobes, berry red) and **Bog Asphodel** (Narthecium, very common in bogs and marshes, leaves stiff and acute, flowers erect, golden yellow, stamens with white hairy filaments, red capsule, narrow seeds with a hair at each end).

179. The Daffodil Family (**Amaryllidaceae**) differs from Liliaceae in having the ovary inferior instead of superior. In the Daffodil and other species of Narcissus a corona is present, which is short in some Narcissus flowers, but in the common Daffodil attains a considerable length. In the Snowdrop (Galanthus) and the Snowflake (Leucojum) there is no corona, and the parts of the perianth are free.

180. 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. In Crocus (Figs. 63, 79) the flowers are regular, terminal, single or with other (axillary) flowers (each in a spathe) around the central flower. In Iris (Fig. 78) the flowers are in manyflowered inflorescences, with spathes, each spathe enclosing several flowers. In Gladiolus, which has corms like Crocus, the inflorescences resemble those of Iris, but the flowers are more or less zygomorphic (owing to the curved and unequally lobed perianth) and each flower is in a separate spathe.

181. The Orchid Family (Orchidaceae) is a very large one, comprising herbs which perennate by means of rhizomes, tubers, etc. The great majority are tropical and epiphytic, supporting themselves on trees by means of clinging roots, and giving off special aerial roots which absorb moisture from the damp air and also contain chlorophyll and are therefore able to carry on photosynthesis. The Orchids of temperate climates are ordinary terrestrial plants, usually with rhizomes, though some have root-tubers (Fig. 55).

The flowers are zygomorphic. The perianth is petaloid and consists of six leaves. The posterior inner leaf (petal) is always more strongly developed than the others, or differs from it in shape, and is called the labellum. Owing to the twisting of the inferior ovary (which can be clearly seen by the ridges on its surface) the labellum comes to be anterior and serves as the landing-place for the insect. In the genera Orchis and Habenari a the labellum has a spur at its base. The andrecium consists of one fertile stamen and two staminodes, except in Cypripedium, which has two stamens and one staminode. The stamens are fused with a prolongation of the flower called the column (gynostemium), which also bears the three stigmas on its apex. The pollen-grains are usually united into masses called pollinia. The pistil consists of three united carpels; the ovary is one-chambered, with numerous ovules on three parietal placentas. The fruit is a capsule containing numerous very small light seeds, and it opens by three slits.

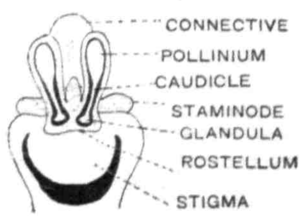


Fig. 137.—Central Part of Flower of Orchis.
Perianth segments removed.

In Orchis (*e.g.* O. mascula, the Early Purple Orchid), which may be taken as a type, the single fertile stamen is the anterior one of the outer whorl (Fig. 80). Pollinia are present. One of the stigmatic surfaces is incapable of being pollinated, and develops into a projecting structure called the **rostellum** (Fig. 137). The pollen-grains are held together by delicate threads which run together at the base of the anther-lobe to form a mucilaginous cord called the **caudicle**, which is attached below to a sticky disc, the glandula, in contact with the rostellum. The two functional stigmatic surfaces are below the rostellum, the two anther-lobes above it, one on each side. These various structures are borne on the column or gynostemium.

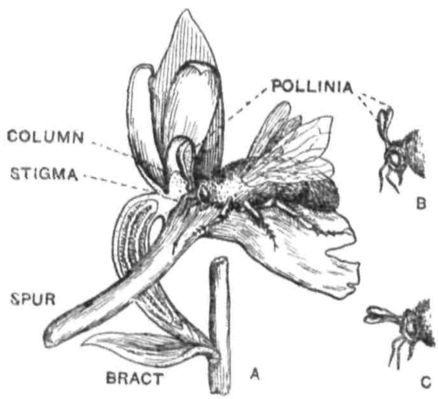


Fig. 138.—POLLINATION OF ORCHID BY A BEE.
At C the pollinia have bent forward and will touch the stigma of the next flower visited.

When a bee alights on the labellum and seeks in the spur of the labellum for the honey, its head comes in contact with the rostellum, and pushes aside the membrane covering the sticky discs of the caudicles so that the insect presses against them. While the insect is piercing the spur the mucilaginous substance of the discs "sets," and when the insect leaves the flower the pollinia are dragged out (Fig. 138). At first they stand erect on the back of the insect, but very gradually they are lowered, owing to hygroscopic properties which their stalks possess, so that when the insect enters another flower they touch the sticky stigmas, which drag off some of the packets of pollen.

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, and the change in position which the pollinia undergo after being removed.

There are five fairly common British species of Orchis. O. mascula, the **Early Purple Orchid,** is the commonest; it has egg-shaped tubers and spotted leaves. O. maculata, the **Spotted Orchis,** and O. latifolia, the **Marsh Orchis,** also have spotted leaves, but the tubers are lobed. **Green-winged Orchis** (O. morio) has green-veined sepals, which arch over the two small upper petals to form a hood. **Pyramidal Orchis** (O. pyramidalis) is known by its pyramidal spike of rosy flowers.

The genus Habenaria resembles Orchis in having spurred flowers. H. bifolia (**Butterfly Orchis**), in wet meadows and heaths, with white flowers; H. conopsea (Fragrant or **Scented Orchis**), in dry pastures, with purple flowers; H. viridis (**Frog Orchis**), in hilly pastures, with yellowish green flowers, are frequently met with. The genus Ophrys includes the **Bee Orchis** (O. apifera), the **Fly Orchis** (O. muscifera), and the **Spider Orchis** (O. aranifera), all found in limestone districts; the Bee Orchis is interesting in being self-pollinated, the pollinia falling over on the stigma.

Bird's-nest Orchis (Neottia nidus-avis) is a total saprophyte, growing in woods.

There are two species of **Twayblade** (Listera). L. ovata is found in woods and pastures; L. cordata in mountain woods and moors. Two species of Epipactis, with green or greenish purple flowers, Epipactis latifolia in woods and E. palustris in marshes, are fairly common; they are visited chiefly by wasps. Spiranthes autumnalis (**Lady's Tresses**), with white flowers, is found on hilly pastures in England and Ireland. In Cephalanthera grandiflora (**White Helleborine**), which occurs in woods in limestone districts, the flowers are self-pollinated.

182. 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 wide distribution over the earth.

Grasses are mostly herbaceous plants, though a few tropical types have hard woody stems (Bamboos, etc.). The stems are usually hollow and branching rarely occurs in the upper parts. The leaves are in two opposite rows, alternate, and each leaf has a basal sheath, usually split down on the side opposite the blade; at the junction of sheath and blade there is usually a collar-like outgrowth (ligule). Some grasses are annual, but most are perennial and have either rhizomes, runners, or suckers, or develop a tufted habit by copious branching at the base.

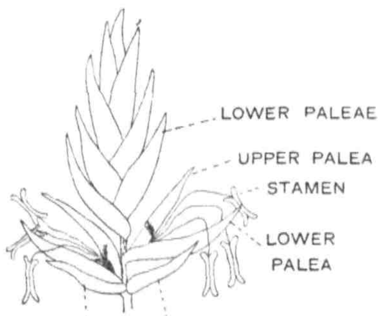


Fig. 139.—TYPICAL SPIKELET OF A GRASS.

The flowers are arranged in spikes (spikelets) which are grouped in various ways to form a compound inflorescence. In Wheat, Perennial Rye-grass, etc., the spikelets are arranged on a main axis forming a compound spike. In many other species the spikelets are borne on numerous branches given off from the main axis; in these forms the inflorescence is a panicle of spikelets which may be loose, as in Oat, or close and cylindrical owing to the shortness of the branches, as in Fox-tail and Timothy-grass. The spikelet consists of a slender axis bearing a number of scales in two rows (Figs. 139, 140). The lowest scales, one on each side, are barren, *i.e.* have no flowers; they are called the *glumes*. The other scales are bracts with flowers in their axils, and are called the lower or *outer paleae* or *flowering glumes*. The lower palea sometimes bears a long bristle called an *awn* (Fig. 140).

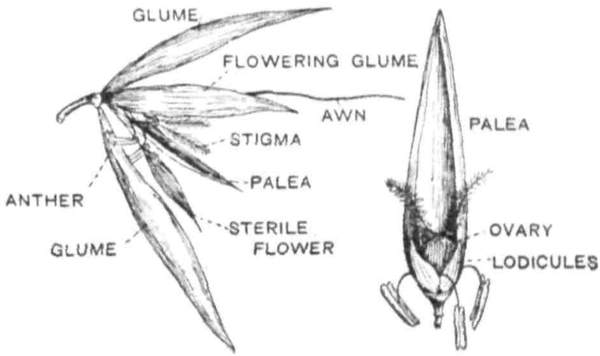


Fig. 140.—SPIKELET AND FLOWER OF THE OAT.
The structures called "glume," "palea," and "lodicules are bracts.

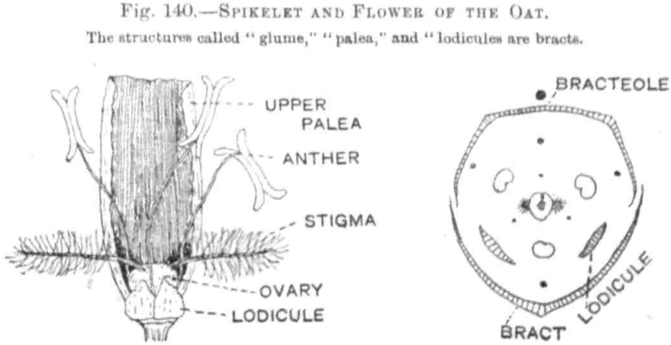


Fig. 141.—TYPICAL FLOWER AND FLORAL DIAGRAM OF A GRASS.
Lower palea removed.

The number of flowers in a spikelet varies: there may be only one perfect flower; sometimes two or more of the flowers are rudimentary, as in Oat (Fig. 140). The axis of the flower bears a scaly bracetole called the *upper* or *inner palea*; it is opposite the bract or lower palea (flowering glume). The flower, lying between the upper and lower paleae, has usually three hypogynous stamens, sometimes only two. The stamens have long slender filaments, and the anthers are versatile—*i.e.* the filament is inserted at about the middle of the anther so that the latter readily swings about. The pistil consists of one carpel, but bears usually two feathery stigmas; the ovary contains a single ovule. The fruit is a grain (caryopsis) and the seed is endospermic. At the base of the ovary on the anterior side there are two little scales called *lodicules* (Figs. 139, 141); these are probably the innermost bracts, but may possibly represent a rudimentary perianth.

The flowers are adapted for wind-pollination. At the time of flowering the lodicules swell and force the bract and bracteole apart, the stamens elongate, the anthers hang out, and the pollen-grains blown about by the wind are caught by the feathery stigmas.

INDEX.

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