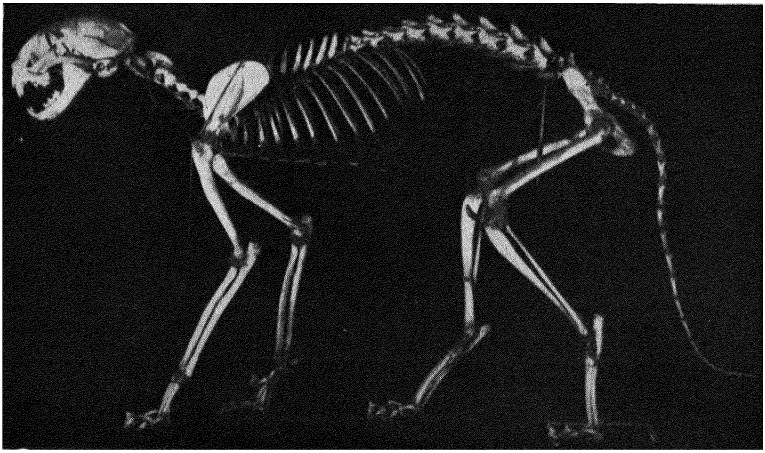
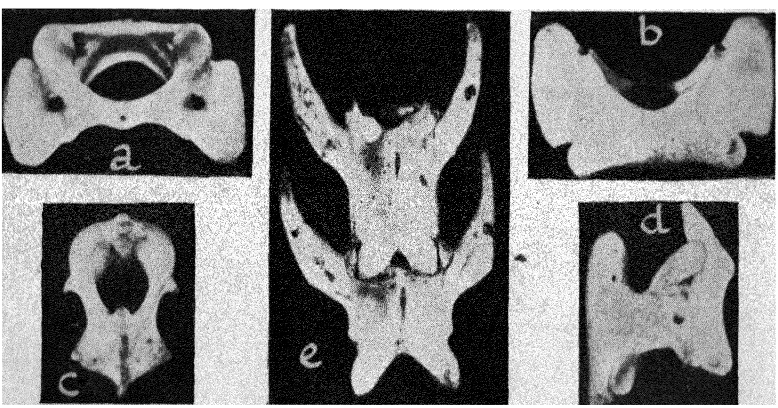
PLATE I



SKELETON OF DOMESTIC CAT



VERTEBRÆ OF CAT.

a, b. Two views of atlas vertebra showing sockets for skull.
c, d. Two views of axis vertebra showing peg which passes through the atlas.
e. Two mid-lumbar vertebræ.

BIOLOGY
BY DISCOVERY

BY

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LONDON & TORONTO
J. M. DENT & SONS, LTD

First Published 1929

Printed in Great Britain by
UNWIN BROTHERS LIMITED, LONDON AND WOKING

PREFACE

In writing this elementary book on Biology the authors have attempted to bridge the gap between simple books on Nature Study and formal textbooks of Botany and Zoology, and to produce a book the usefulness of which is not limited to schools of one particular type.

As far as possible, the use of technical terms has been avoided, for the authors deem it of the greatest importance that boys and girls should be able to describe an animal or plant accurately and concisely in simple language. Such descriptions further intelligent interpretation of observations, whereas the use of the correct technical terms is often fortuitous, and may be a hindrance, rather than a help, to deduction.

Teachers working on the Dalton Plan or modifications of it will find that the chapters, questions, and additional practical work may be readily divided into suitable assignments. In order that experiments may be made at home and in schools handicapped by lack of the usual apparatus, the materials suggested for use in the experimental work are such as may be easily acquired at a minimum cost.

The book contains material sufficient for the Junior Certificate Examinations in Biology or Natural History, and also for the Biological Section of the General Science papers, of the English universities. The authors wish to express their thanks to the School Examination Boards of the Universities of London, Oxford and Cambridge, and Durham, and to the Joint Board of the Northern Universities, for permission to include questions from the examination papers set by them.

The authors desire also to thank Dr. H. Gordon Jackson, Birkbeck College, Professor of Zoology in the University of London, for permission to photograph the skeleton of the domestic cat; Mr. Charles Dobb for his painstaking preparation of the photographs; and Miss Nora Legg, of Selborne, for collecting many of the specimens from which the diagrams were made.

E. G.

E. A. P.

LONDON, 1929.

CONTENTS

BIOLOGY BY DISCOVERY

CHAPTER I

HOW TO STUDY BIOLOGY

ARE you alive? You have no doubt whatever about the answer to this question. Can you be equally sure that other things are alive? Since Biology (Gk. *bios*, life; *logos*, discourse) is the science concerned with living things, a biologist should know how to distinguish a living thing from a non-living one.

By speech or movement, you could easily show that you have life. Many living things, unable to speak, can move very quickly. For instance, spiders and flies and tiny water plants travel from place to place with great speed. On the other hand, trees, though living, remain fixed in the soil. The air, the sea, and the earth are constantly moving, whereas houses and chairs cannot move themselves. Thus we may say *some* living things and *some* non-living ones move, while others do not, and so we cannot decide whether a thing has life by finding whether it is able to move. In the same way, if you test many other differences that seem to be obvious, you will find that there are exceptions to them, and that the only statements true for *all* living things are:—

1. They breathe.
2. They feed by taking food inside their bodies.
3. Their food is unlike at least some of their body substance.
4. They grow by distributing the food within them to all parts of the body and by changing it into body substance.
5. They are capable of reproducing themselves.
6. They are irritable, that is, they are sensitive in some way or other to any influences acting on them.

It is insufficient to say merely that living things feed and grow, for crystals also feed and grow. The differences lie in the manner of feeding and growth, and in the kind of food. Crystals add food to their surfaces and so grow by external addition, while living things can grow only by addition from within. Crystals must add layers of material similar to that composing them: soda crystals cannot be grown in a solution of common salt. No crystal is able to change different food into substance like its own, whereas animals transform their various foods into such diverse structures as hair, nails, flesh and bone; and plants, from solutions of mineral salts, and from carbon dioxide, are able to produce such different materials as cork, flower petals, gum, indiarubber, and starch.

Animals and plants have already been mentioned frequently, for they are the two great classes into which living things are divided. How do the members of one class differ from those of the other? Since every living thing is either an animal or a plant, we have to look for differences that will enable us to distinguish between such widely differing animals as human beings, flies, worms, sponges, and microscopic animals on the one hand, and on the other such different plants as an oak, the blue mould which grows on cheese, and the microscopic swimming plants.

Most animals feed on solids, but no plant can feed on solid food. The few plants able to catch insects and use them as food must first pour out a juice to dissolve the softer parts of the insect's body. The solution is then absorbed by the plant.

Some animals, such as the spider, gnat, and flea, suck the blood from their prey and never eat the solid parts; others, like the green-fly and the butterfly, feed on the juices of plants; while still others, like the house-fly, are able to pour out a liquid which dissolves the food, and the insect sucks up the solution. There are, then, many animals that never take solid food, and to decide that these are animals, we have to consider their structure. No one would think of describing the fly and the flea as plants, because their structure so closely resembles that of many well-defined animals, and is totally unlike that of any plant.

Certain less commonly known plants live on animals. You may have seen a dead fly or fish with a mass of white "mould" around it. This is a collection of thread-like plants absorbing juices from the animal's body, though these juices are probably changed before they enter the plant. Plants cannot directly absorb the blood of animals, as other animals can.

All animals need more complex food than *green* plants require. These need only the gas carbon dioxide, and solutions of simple mineral salts, from which they can build up the very complex substances that all animals need but are unable to make for themselves. Thus all animals depend on plants for their food, either directly, as the sheep does when eating grass, or indirectly, as you do when eating the sheep.

All plants and all animals breathe constantly, day and night. Some microscopic plants swim; some animals settle down soon after they are formed and remain fixed until they die.

We see, then, that it is impossible to find any one difference that will distinguish *all* animals from *all* plants. A living thing that eats a solid is certainly an animal, but one which takes its food in solution *may* be an animal or *may* be a plant. To decide in which class to place it, we must examine its habits, development, and structure, microscopically if necessary, and then place it in the class it most closely resembles.

EXERCISES AND QUESTIONS

1. What is the difference between the meaning of "dead" and "non-living"?

2. How would you try to find whether an object were living or non-living?

3. Give examples of non-living things which move from place to place, and of living things unable to do so.

4. Explain why an alum crystal is said to grow when it adds coats of alum, whereas a boy does not grow when he puts on coats.

5. A spider feeds on flies. A pitcher plant feeds on flies. Why is not the spider a plant?

6. Why is it correct to say that a frog eats flies, but incorrect to say that spiders and some plants eat flies? Make the statement correct.

7. How would you try to discover whether a living thing were a plant or an animal?

8. Make a list of the resemblances between plants and animals.

9. Explain the difference between *sense* and *sensitivity*.

10. Rule your paper into two columns. Head one **ANIMALS** and the other **PLANTS**, and put the following living things into the appropriate columns: Human being, ant, oak, tortoise, mushroom, moss, grasshopper, elephant, snail, sunflower, elm, robin, sea anemone, fern, tadpole, seaweed, snake, flea, herring, willow, lobster, worm, sundew, starfish.

CHAPTER II

HOW PLANTS AND ANIMALS ARE CLASSIFIED

A GROCER has in his shop many different kinds of foods. Although all are foods, if he be a business-like grocer he will sort them into groups. A large part of his stock will consist of tinned foods, and he will make separate groups of the tins of biscuits, of fruit, of meat, and of cocoa. He will then sort out the tins of each group, putting together all the tins of peaches, all those of pineapple, and those of pears, so that he can get a tin of any particular kind quickly without having to hunt through all his stock. Moreover, if a customer knows what is meant by "fruit", the grocer need only explain how one kind differs from another without having in each case to say what fruit is.

Similarly, animals and plants are subdivided into groups, so that a description of the group applies to each of its members, and it is only necessary to say, in addition, how the individual members differ.

Just as the grocer may have a large group of tinned fruits and divide them into smaller groups of apricots, peaches, pears, and pineapple, so the two big groups of animals and plants may be subdivided into smaller ones.

If we consider the animals first, you will find that it is possible to divide them into two very big groups, including in one such different individuals as man, the elephant, frog, bird, and fish, and in the other, worms, insects, crabs, snails, and spiders. The members of the first group all have a skeleton inside their bodies; those of the second group either have no skeleton, or, like the crab, have all the hard parts of the body outside, that is, they have an exoskeleton, while the members of the first group have an endoskeleton. One of the best developed parts of the endoskeleton is the spine, which consists of a number of small bones, the vertebræ, and so all the animals with an endoskeleton are put into the group **Vertebrata** (L. *vertere*, to turn), while the others are included in the **Invertebrata.**

Although men, birds, and fishes are vertebrate animals, they obviously differ very considerably from one another, so the Vertebrata are divided into smaller groups of similar animals. The Invertebrata, too, are divided into smaller groups, and in both cases these may again be subdivided. Here we shall mention only the main divisions of both, considering the Vertebrata first.

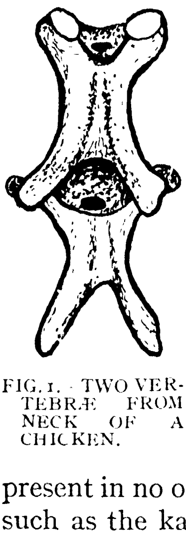

FIG. 1. TWO VERTEBRÆ FROM NECK OF A CHICKEN.

The **Mammalia** form one of the biggest groups of Vertebrata, and include such different animals as men, bats, whales, elephants, and mice. All have a covering of hair, which may be very scanty except over a few areas such as the scalp, or may form a thick covering over the whole body, as in the dog. The mammals (L. *mamma*, milk gland) include all the animals whose young develop partly or completely within the body of the mother, and, after birth, are fed on milk from her glands. These glands are present in no other vertebrate group of animals. Some animals, such as the kangaroo and opossum, have pouches into which the milk glands open and the young ones are put as soon as they are born. The pouched animals are called marsupials (L. *marsupium*, a pouch). Very few mammals lay eggs, but the duckbill, a marsupial, lays an egg containing the young animal partly developed, and places it in the pouch to hatch. All mammals have a partition, the diaphragm, stretching across below the ribs and dividing the trunk of the body into two parts, the thorax and abdomen.

The birds are collected in a group named the **Aves** (L. *avis*, a bird). They are distinguished from all other animals by their covering of feathers and by their fore-limbs or wings corresponding to our arms. Although a few mammals, such as bats and flying squirrels, have wings, their structure is very different from that of birds' wings.

Birds lay eggs, but the young bird does not begin to develop until after the egg is laid, and will do so then only if the egg be kept warm naturally by the bird, or the tropical sun, or artificially in an incubator.

The birds and mammals are the only vertebrate animals which always have warm blood, and their temperature varies very little when they are healthy. All the other Vertebrata are cold-blooded animals, that is, they have colder blood than the birds and mammals, and their temperature changes with that of their surroundings.

Snakes, lizards, crocodiles, and tortoises are amongst the animals included in the **Reptilia.** The Latin word for snake, *reptilis*, is derived from a word meaning to creep. In addition to their endoskeleton, all the reptiles have an exoskeleton of thin tough scaly plates, as in the lizard and snake, or of hard plates like those of the tortoise and crocodile. Though many reptiles spend much of their time in water, none of them can breathe beneath its surface, but have to raise the nostrils out of the water to obtain air.

Some reptiles are hatched from eggs; others are born after partly or completely developing within the mother.

Frogs, toads, and newts are the most commonly known members of the group **Amphibia** (Gk. *amphi*, both; *bios*, life). These animals spend the first part of their life in the water, and have special breathing structures, the gills, which enable them to breathe under its surface. During development the gills are lost, and the animal can live on the land. It is still able to spend a considerable time in the water, breathing through its skin, but sooner or later it has to raise its nostrils above the surface to breathe in more air. Other changes accompany the loss of the gills, and are often very striking, as, for example, the change of a tadpole into a frog. A change from one form to another in the life of an animal is called a metamorphosis (Gk. *meta*, after; *morphe*, form).

Some of the Amphibia lay their eggs; others retain them until they are hatched.

Fishes form a large vertebrate group, the **Pisces** (L. *piscis*, a fish). Many of them resemble the reptiles in having scales, or horny or bony plates, but one great difference lies in the fact that all fishes have gills which are retained and used throughout the life of the animal. A very few fishes, such as the Australian lung fish, have a special structure enabling them to breathe while coiled in the mud during the dry season, but these fishes retain their gills and use them when water returns.

In addition, the fins of fishes are supported by sharp spines, the fin rays, and so differ in this respect and in their arrangement from the soft fins of the amphibia.

Most fishes lay eggs, but in a few cases these develop in the mother's body, and the young are then born.

The Invertebrata are on the whole less widely known than the vertebrate animals, and here we shall refer only to a very few groups of them—those including insects, spiders, crabs, worms, and snails.

The largest group of the Invertebrata is called the **Arthropoda** (Gk. *arthros*, joint; *pous*, foot). It includes all the invertebrate animals with segmented bodies and paired limbs. If you look at a caterpillar you will see that its body appears to be divided into a number of circular bands. Each of these is a segment, and on the under surface of some of these segments you will find pairs of legs. The caterpillar very clearly illustrates the meaning of "segmented body and paired limbs".

The mouth parts of the Arthropoda, as you may see if you watch a house-fly feeding, are outside the head of the animal.

Amongst the animals included in this group are the insects, spiders, and crabs, but these are put into smaller groups because they differ from one another very considerably.

The **Insecta** (L. *secare*, to cut) include all the Arthropoda which have a body divided into three main parts, the head, thorax, and abdomen, and have only six legs. Ants, fleas, and flies are examples of insects. If you look at any insect carefully, you will see mouth parts and two prominent feelers or antennæ on its head. The eyes are always on the head, and can easily be seen in the fly, beetle, or wasp. Next to the head are three segments, each bearing a pair of legs. These segments form the thorax. Sometimes, as in the wasp, a narrow waist separates the thorax from the abdomen, but in many insects there is no waist. The abdomen consists usually of eleven segments, but often it is impossible to distinguish all of them on the outside of the insect. In the details of their structure insects vary considerably. Some, like butterflies, have two pairs of wings; others, like house-flies, have only one pair; while others, like the flea, have no wings at all. If wings, or structures such as wing cases or balancers taking the place of wings, be present, they are always in pairs on the thorax, one pair on the third segment, and the other, if developed, on the second.

Whatever differences there may be between the various kinds of insects, the Insecta differ from all other groups in having the body divided into head, thorax, and abdomen, the thorax always consisting of three segments, each having two legs. Insects also have special breathing tubes which cannot, in most cases, take in air dissolved in water. Aquatic insects, with the exception of a few like the caddis-worm, come to the surface to breathe, or must take their own supplies of air into the water.

Spiders are like insects in being unable to breathe under water unless they carry bubbles of air with them, but they differ from the Insecta in that there is no visible division between the head and the thorax which bears four pairs of legs. On account of these and other smaller differences the spiders are included in a division of a group called the **Arachnida** (Gk. *arachne*, spider). In place of the antennæ found in insects, the spiders have two pairs of weapons which pierce and paralyse the prey and squeeze its juices into the tiny mouth of the captor. The water scorpions belong to another division of the Arachnida.

Shrimps, lobsters, crabs, crayfishes, ships' barnacles, and water-fleas are members of the group **Crustacea.** This group is divided into two because the lower members differ considerably from the more highly developed ones. Ships' barnacles and water-fleas are examples of the lower ones, but since their structure is so specialised, the characters distinguishing only the higher forms will be given here. These have segmented bodies; the last segment, the telson, is forked and acts like a paddle. You can see this quite well in the prawn and crayfish. Each segment of the abdomen as well as of the thorax bears a pair of forked appendages, some of which are used in feeding, others for walking, and others for swimming. The head is joined to the thorax as in the Arachnida, but the segmentation of the body is usually very distinct, and the presence of appendages on the abdomen makes a Crustacean readily distinguishable from a spider.

Snails belong to a division of the **Mollusca** (L. *molluscus*, rather soft), a large group including the octopus, cuttlefish, slugs, mussels, and many other creatures of very diverse form. All have soft bodies with part of the under surface flattened to form a "foot", by means of which the animal moves, burrows, or attaches itself. On the upper side of the body the skin grows to form a flap at each side, and this flap folds over, enclosing a cavity called the mantle cavity, in which breathing takes place. Some Mollusca, like the snail and mussel, build shells which may be big enough to enclose the animal. The shell of others is a tiny structure carried at the end of the tail, as in one kind of slug, or is quite inside the animal, as in the cuttlefish.

The earthworm may be seen so frequently that people who have never examined one of these animals call almost any animal of similar shape a "worm". For example, a slow-"worm" is a lizard, a wire-"worm" is the early form of the skip-jack beetle, and like the caddis-"worm" an insect. A true worm never changes its form after it has become worm-like, and the possession of a skeleton excludes the slow-worm from this class.

Worms are soft-bodied animals without any limbs or shells, and their bodies are usually elongated.

If you look at an earthworm you will find its body is divided into a number of circular bands, that is, it is segmented. The segmented worms or **Annelida** (L. *annulus*, a ring) include earthworms and leeches, both of which are useful to man.

The unsegmented worms include the **flat-worms** and the **round-worms**: their names partly describe the shape of these worms.

Amongst the flat-worms are many creatures which are very harmful to cattle and to man. For instance, the tape-worms which live inside human beings and various mammals, and the liver-flukes which infest the sheep's liver, are very injurious. Tape-worms often have jointed bodies and so appear segmented, but the joints, unlike segments, can be thrown off and grow into new animals.

The round-worms also cause disease in animals. You will almost certainly find some round-worms if you cut open a herring and expose its internal organs.

From the various types of animals which are wrongly called "worms" it is easy to see that we cannot put an animal into its correct group merely on account of its shape. We must examine its whole structure, and in very many cases the life history of the animal must be known as well in order to determine which group it resembles most.

Plants are divided into groups in much the same way as animals, and again it must be remembered that only the big obvious differences or similarities will be mentioned here, because much of the detailed structure, on which classification finally depends, is beyond the scope of this book.

At whatever time of the year you look at ferns, mosses, or seaweeds, you will never find any flowers on them, whereas you can find plum blossom, willow catkins, and primroses in spring, and various other flowers throughout the year. Plants then may be divided into two big groups, the **Flowerless** and **Flowering** Plants.

After the flower has died you may find the fruit, which goes on growing, and you have seen the seeds inside tomatoes, gooseberries, pea-pods, and apples. Plants which enclose their seeds are **Angiosperms** (Gk. *angeion*, a case; *sperma*, a seed).

Pines, firs, larches, and a few other trees do not enclose their seeds within a fruit wall, and these plants are **Gymnosperms** (Gk. *gymnos*, naked.)

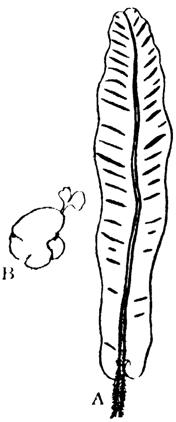

FIG. 2.

A. Back of frond of Hart's Tongue Fern showing areas in which spores are produced. $\times \frac{1}{5}$.[1]

B. Prothallus (gametophyte) of Male Fern with first leaf of sporophyte. $\frac{1}{2}$.

Flowering Plants then are subdivided into Angiosperms and Gymnosperms, and these are further divided into Families, and into still smaller groups called Natural Orders. This further subdivision depends upon the structure of the flower, and the characters of a few Natural Orders will be given at the end of the book.

The subdivision of the Flowerless Plants depends mainly on the mode of development of the plant and its detailed structure. Since neither is within the province of this book, the main groups will be mentioned with the more obvious features which help to distinguish them from the others.

The **Ferns** are, perhaps, the most widely known Flowerless Plants. Most ferns have large green leaves or fronds, often very much subdivided, and borne on a stem which may be more than twelve feet high, as in the tree-ferns, or may have only a few inches rising above the ground, as in the lady-fern, or may be entirely underground, as in the bracken. During the year you may see on the backs of some fronds, or on the margins of the fronds of other ferns, brown patches from which a very fine powder may be removed. Each particle of powder is a spore,[2] and when planted under favourable conditions will grow into a tiny plant quite unlike the original fern. This tiny

[1] Throughout the book, the indicated reduction or magnification of the figures is approximate, and the reader should remember that living things, even of the same species, vary considerably in size

[2] The difference between a spore and a seed is shown in Chapter V.

plant is called the prothallus, or the gametophyte (Gk. *gamos*, marriage; *phyton*, a plant), and in time it may produce, or help to produce (in a manner to be explained in Chapter V), new spore-bearing fern plants or sporophytes. Thus in the course of its life history the fern has two forms, the smaller one being usually overlooked, partly on account of its size and partly because in some ferns it grows beneath the surface of the soil. These two fern individuals are distinct, and several sporophytes may grow out from one gametophyte. Thus the process cannot be compared with the metamorphosis of the tadpole, or of the caterpillar, in which the single individual changes its form, but remains one and the same individual throughout. The fern gametophyte and sporophyte are two generations of plants, and since the gametophyte produces sporophytes, and these form spores which develop only into gametophytes, the plant is said to complete its life history by an alternation of generations. You may often see the gametophytes growing on the surface of damp soil under a male fern which has shed its spores. The plants are light green, usually less than half an inch across, and lie flat on the soil.

A few ferns, such as the royal fern, the adder's tongue, and the water-ferns, produce their spores on special leaves or parts of leaves from which the flat green leafy part is absent, so that the spore-bearing part does not look like a leaf.

The **Mosses** form another group of the Flowerless Plants. The moss plants are usually small, and have a vertical axis, or stem, bearing leaves and sometimes branches. The leaves are spirally arranged, and are small and entire—that is, not subdivided. Like the Ferns, the Mosses have an alternation of generations, but there is a marked difference. The moss plant is the gametophyte: the fern plant the sporophyte. The small capsule which you see growing on a moss is the main part of the sporophyte. At the top of this capsule you may often find a thin membranous cap. This is the cover which protected the sporophyte when it started its growth at the apex of the gametophyte. The cover was soon burst and carried up as the stalk of the sporophyte grew. The spores are formed in the capsule, and when shed each grows into a fine branched structure, a protonema (Gr. *protos*, first; *nema*, thread) on which buds develop and grow into new moss plants. Thus one spore may give rise indirectly to several gametophytes, whereas a fern spore can develop into only one.

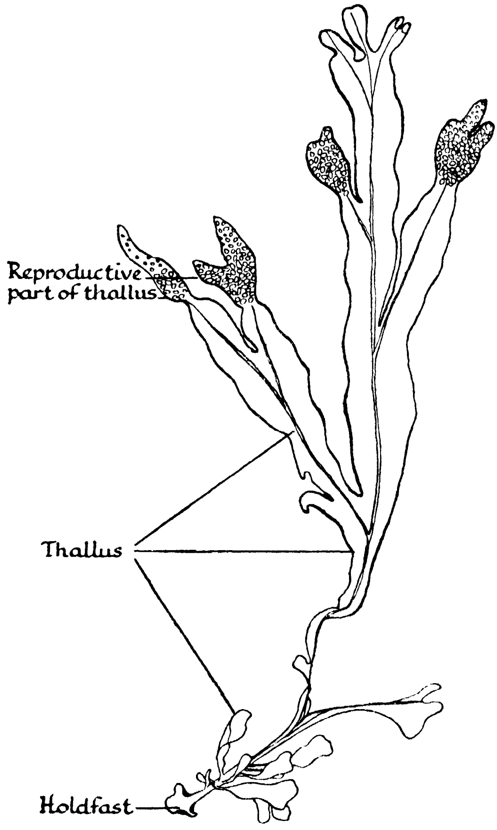

FIG. 3.—A SPECIES OF FUCUS—A COMMON ALGA.

The **Liverworts** form a group containing some plants which look very much like mosses, though the details of their development are different. Liverworts branch by dividing into two at the apex, whereas the main stem of the moss does not fork. Like the moss, the liverwort plant is the gametophyte, and the most commonly known liverworts have no leaves. The plant consists of flat green plates on the surface of damp soil, and you may often find them on well-watered soil in flower-pots, and on the banks of ditches and streams. A plant body which is not divided into stems and leaves is spoken of as a thallus (Gk. *thallos*, a young shoot). The liverwort thallus forks repeatedly, and so spreads in all directions. A few liverworts have leaves arranged in two or three rows, but even these leafy plants grow horizontally, not vertically like mosses.

Like that of the moss, the liverwort sporophyte consists mainly of the capsule, but this does not grow through the protecting cover of the gametophyte until the spores are ripe. The spores of some of the liverworts develop into branched protonemata, from which several gametophytes grow, but in most liverworts the protonema is not well developed.

Neither the ferns, mosses, nor liverworts have true roots. They have structures called rhizoids, which usually grow from the stem at the base of the leaves, or under the thallus, and do the work of roots.

All the seaweeds, and many plants found in fresh and stagnant water, are included in a large group, the **Algæ** (L. *alga*, a seaweed). Some are floating, others can swim freely, and others are attached to stones or any convenient objects by discs or branched outgrowths. The part attaching the plant is called a "holdfast". The habits and structure of the Algæ vary considerably. Many have no definite alternation of generations, and many produce no spores. Examples of Algæ are the bladder-wrack, the "bootlaces" or cord-like seaweeds, the sea-lettuce, usually to be found on the shore at most seaside places; the green threads growing on damp flower-pots, or forming a scum on pond and ditch water, particularly in the autumn and spring; and the green specks on damp walls out-of-doors and on the bark of trees. Two Algæ are described in Chapter III.

The **Fungi** form a very interesting group of plants because they have developed on entirely original lines and differ from the great majority of plants in needing a special diet. Most of the plants already mentioned contain a certain green pigment which helps them to build up their food materials. No fungus has this pigment, and so the fungi have to get their food already built up either by growing on living plants or animals and absorbing it from them, or by living on decaying plant or animal matter. Soil spoken of as humus, which consists largely of decaying leaves, is especially rich in fungi. Since the fungi do not build up food materials, they do not need the apparatus which helps in the upbuilding, so their structure is very different from that of most other plants. They consist of threads or hyphæ, which remain distinct in the simple forms, such as the mould you may find on cheese or jam, or which may become interwoven to form a dense compact mass as in the mushroom and "toadstools". The fungi reproduce by spores, and have no definite alternation of generations.

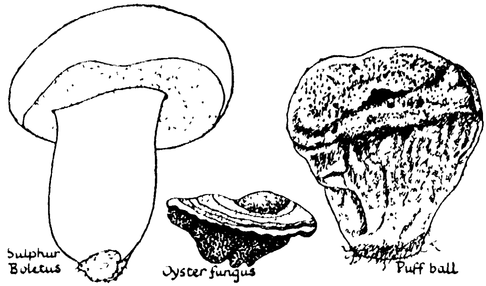

FIG. 4.—FUNGI.

The group **Bacteria** is made up of microscopic organisms which resemble the fungi in being unable to build up food for themselves. Many bacteria get their food from living animals, and do the animal considerable harm. Such bacteria are often spoken of as "germs". Other bacteria while feeding produce substances useful to man; they help to ripen cheese, and to make dead leaves part of the soil by rotting them. Bacteria are the smallest organisms known. Many of them can move, and, because of this and their inability to build up food, they were originally classed with the animals.

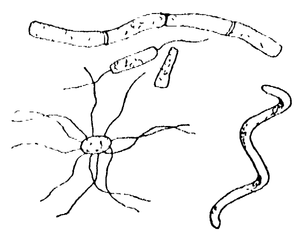
FIG. 5.—DIFFERENT TYPES OF BACTERIA.

In other respects, however, they resemble the fungi and some of the simplest algæ, so that they are now included with the plants.

Let us consider again our simile of the grocer and his problem of sorting out and classifying the foods. What will he do with the café-au-lait? It has some of the properties of coffee and some of the properties of milk. Will he put it in his list with the other kinds of coffee, or with the condensed milk, or will he give it a section to itself? On the whole it resembles coffee rather more than it resembles milk, so he will probably include it with the coffee.

Similarly, amongst animals and plants, individuals are found possessing the characters of two groups, and biologists may differ in classifying such individuals: some put them into one group, some into the other, while some make an entirely new group for them.

PRACTICAL WORK

Visit the Zoological Gardens and try to find animals you would include in the following groups:

1. Cat-like animals.
2. Sheep-like animals.
3. Rat-like animals.
4. Insecta.
5. Arachnida.
6. Reptilia.
7. Amphibia.
8. Aves.
9. Watch the fishmonger's shop and find which Crustacea he has.

Visit the nearest ditch or pond and try to collect specimens of:

10. Algæ. 11. Liverworts. 12. Flowering plants.

13. Collect some fern spores, spread them on damp soil in a flower-pot saucer, and watch for the growth of the gametophyte or prothallus. It may take some months to grow, but keep the soil moist all the time.

14. Carefully remove the head from a ripe mushroom and stand it, with the light surface uppermost, on a sheet of white paper. Leave it for twenty minutes, and then lift it straight up from the paper. If you see no result, replace the head and leave it for a longer time. Try

to account for the result, and say where the spores of the mushroom are formed.

15. Draw large diagrams of two mosses showing where the spores are produced, and how they are shed.

16. Sketch the thallus of three seaweeds you have found growing between high- and low-tide marks.

17. Draw clear diagrams to show where the spores of the bracken, hart's tongue, and maidenhair ferns are formed.

18. Draw the fruit (a cone) of a pine-tree and of an apple, showing the seeds in each.

EXERCISES AND QUESTIONS

1. Why should plants and animals be subdivided into groups?

2. Arrange the following animals in columns headed by the name of the group in which the animals are included: Snake, spider, owl, rabbit, kangaroo, frog, adder, wren, crocodile, elephant, ostrich, tomtit, whale, toad, tortoise, salamander, scorpion, slow-worm.

3. Classify the following animals: Bat, sparrow, snail, prawn, herring, flying squirrel, lobster, wire-worm, octopus, tape-worm, eel, caddis-worm, cray-fish, crab, dog-fish, slug, earthworm, salmon, duck, mussel.

4. Make two columns: Head one **Flowering Plants** and the other **Flowerless Plants,** and put into the appropriate columns: The daisy, beech, elm, pine, larch, rose, fern, plantain, Christmas-tree, moss, holly, asparagus, mould, mistletoe, mushroom, sea-lettuce, cabbage and carrot.

5. Why is "asparagus fern" a very bad name for the plant?

6. To what group does the bat belong? What are the reasons for including it in this group?

7. Give as many examples as you can of marsupials. How does a marsupial differ from other mammals?

8. Why is the spider put in a group apart from the insects?

9. The frog, lizard, and mouse are four-legged animals. Why are they included in different groups?

10. Mention some so-called "worms" which are not true worms, and say why the name is not a good one for the animals you mention.

11. Write down as many kinds of animals as you can that undergo a metamorphosis.

12. What are gills? Name different kinds of animals having gills.

CHAPTER III

HOW PLANTS AND ANIMALS ARE BUILT

EVERY building is made by putting together a number of units of structure. The units may vary considerably in size, from the huge granite blocks used for the temples and pyramids of Egypt to the minute grains of sand you use for your castles at the seaside; or, in modern building, from standard bricks to the tiny stones and grains of cement found in concrete.

Every living structure is also built up of units, or cells, but these are smaller than most of the units of your sand castle. Look at a one-tenth division on your ruler, and try to imagine this divided into ten. You will then have some idea of one-hundredth of an inch, the diameter of a fairly large cell, and will understand that the units which make up the animal or plant can be studied only with the aid of a microscope. If, too, you measure a worm and use a little arithmetic, you can get a very rough idea of the millions of cells built together to make its body.

In the same way that it is possible to have a single grain of sand, or a single brick, it is possible to find certain cells which are alone, and we are going to consider three of these—one a plant and the others animals.

Since a single cell is so minute, a microscope is necessary to find out its structure and habits, and here it is possible to get a wrong impression, which must be avoided in all microscopic work. The ordinary microscope will show you only one level of an object at a time. For a different level the microscope must be readjusted. Look directly down at a book lying on the table and you will see only the top cover. Open the book and look directly down at the first page and you will see only that, and similarly you can work through the whole book. In the same way, by gradually bringing the lens of the microscope nearer the cell underneath it, you can work from the top level to the bottom level of the cell, and though you can see only one level at a time, you must remember that the others are there, and that a cell is a solid and not merely a surface; it has length, breadth and *thickness*. In diagrams a clearer idea of the structure is usually given if a section—that is, a view of

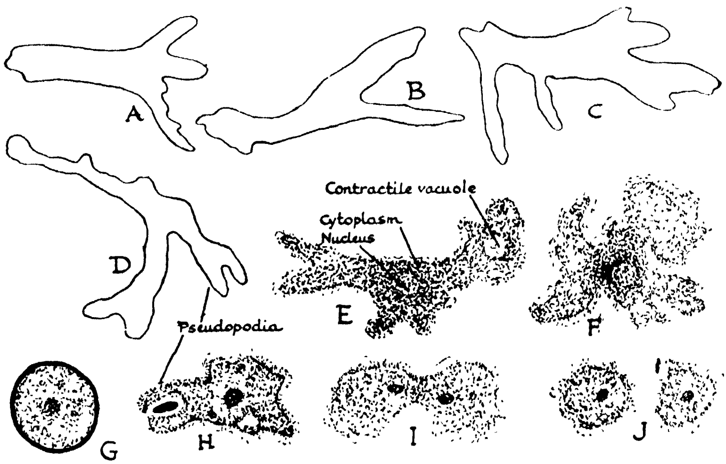

FIG. 6.—*AMŒBA*.

A–D. Changes in shape of animal drawn at intervals of two minutes.
E, F. Nucleus embedded in cytoplasm. × 80.
G. Encysted *Amœba*.
H. Pseudopodia enclosing food. } Semi-diagrammatic.
I, J. *Amœba* reproducing by fission.

one level only—is drawn, but the whole cell always has thickness.

Amœba

Remembering this, look at an *Amœba* under a microscope. The *Amœba* is a small, colourless animal which you may find in freshwater ponds or ditches, or on damp earth. It is only about one-hundredth of an inch in diameter, so you may have to hunt microscopically through many drops of water to find *Amœba.*

Watch the animal, and you will see that its shape is constantly changing, and because of this it was named *Amœba* (Gk. *amoibe,* change). It has no definite boundary to keep it in any particular shape, but is merely a jelly-like mass, moving by pushing forward part of its substance and drawing the remainder after it. There is no head nor tail, so the animal can move in any direction without first turning round. The jelly-like substance is spoken of as **cytoplasm.** Embedded in it is a denser oval body, the **nucleus.** Because the nucleus is denser, it allows less light to pass through it, and so it appears darker than the surrounding jelly, just as two thicknesses of paper held up to the light appear darker than one. The cytoplasm and nucleus together are called protoplasm (Gk. *protos,* first; *plasma,* form).

When a little piece of cytoplasm is torn from the *Amœba* the animal may continue to live, but when the nucleus is removed, the cytoplasm dies. There is no living thing, nor part of one, with which the nucleus can be correctly compared; it is unique, and it plays an important part in the reproduction of the animal.

Near the surface, an opening alternately appears and disappears. This is a **contractile vacuole,** so called because the first observers thought it merely an empty space which was made by contraction of the cytoplasm. Actually, waste liquid, which would be injurious to the *Amœba,* is collected in the contractile vacuole and expelled through the surface.

Scattered through the cytoplasm are small, dense granules of food material which the *Amœba* may store for a time as a reserve, as we store fat and other substances, to be drawn upon in time of need.

Food and Feeding.

The *Amœba* feeds on minute water plants which are smaller than itself. It thrusts out "arms" of cytoplasm and these gradually meet, enclosing the plant. The "arms" are called pseudopodia (Gk. *pseudes*, false; *pous*, foot), and the direct inclusion of solid food in the cytoplasm is described as *ingestion.* Within the animal the food is dissolved, that is, it is *digested.*

BREATHING.

The *Amœba* breathes all over its surface. What breathing is, will be considered later in this chapter.

REPRODUCTION.

As the animal feeds and increases its body substance it grows, and, at first sight, there seems to be no reason why it should not grow indefinitely. Actually, however, if the *Amœba* were to exceed a certain limited size its volume would become too great compared with its surface, which would then be incapable of supplying the animal's needs. You may verify the fact that the volume increases more rapidly than the surface by working out the volumes and surface areas of various solids. Consequently, when the limit of growth is reached, or perhaps even before if the animals have plenty of food, the *Amœba* divides into two. First of all, the nucleus divides and then the cytoplasm collects round each of the nuclei and finally narrows between them till two separate *Amœbæ* are formed. This process is not a mere haphazard splitting; the material of the nucleus is divided by a complicated method into two similar halves.

Because of this method of reproduction, by which the *Amœba* continues to live as two individuals instead of one, it is spoken of as immortal. If it live in good conditions, it will go on growing and dividing every few days, and there is no reason why it should die. Actually, however, thousands of *Amœbæ* are swallowed by larger water animals, so that accidental death is common.

In some cases, after an *Amœba* has been reproducing for some time by the method of simple division or fission, it seems to become less vigorous. When it meets a similar *Amœba,* the cytoplasm of the two animals fuses together, the two nuclei fuse—that is, they join so completely that it is impossible to distinguish the parts contributed by either animal—and the two animals thus form a single one. This process is called conjugation (L. *con*, together; *jugum*, yoke).

The animal formed from the union of the two *Amœbæ* usually rests for a time, and then feeds and divides as before. The union has increased the vigour, and similar invigoration may sometimes be produced by putting a little weak beef-tea or other stimulating food solution into the water in which the animal is living.

There is one event which you would expect to be a great catastrophe in the life of any water animal, and that is drought. To the *Amœba* this is merely an occasion for self-protection; and from its surface it produces a firm covering, in which it remains until it is blown to a damp place or until rain falls. Then it absorbs water through the porous covering or wall, bursts it, and emerges to continue its normal life. When inside the wall it is said to be in an encysted condition (Gk. *kystis*, a bladder).

The *Amœba* is the very simplest type of animal life. It has none of the structures associated with the higher animals—no heart, no lungs, no brain, nor anything corresponding to any of these. Although it has no eyes it is sensitive to light, and will move towards shady places. It will move away from dilute acid or a weak electric current, and it does not mistake particles of sand for food. How it distinguishes such things it is impossible to say. An animal which is sensitive, although it has no sense organs, is described as diffusely sensitive.

Chlamydomonas

Let us now examine a microscopic plant which also consists of a single cell, the *Chlamydomonas* (Gk. *monas*, one; *chlamys*, coat). Collect, from a pond or ditch, water which has green specks in it, and examine it under the microscope. The *Chlamydomonas* is shaped like a lemon and has a definite boundary, the cell wall, which prevents it from changing its shape. Within the cell wall is cytoplasm and a nucleus, as in the *Amœba*, but in addition there is a green structure, shaped like a basin and embedded in the cytoplasm at the wider end of the cell; in much the same way as a sponge cake may be embedded in a jelly. Two long, fine threads of cytoplasm, the cilia (L. *cilium*, eyelash) protrude from the narrow end of the cell, and by their movement the *Chlamydomonas* can swim rapidly in the water. Actually, of course, the *Chlamydomonas* does not move very far in a minute, but if you compare the size of the plant with the

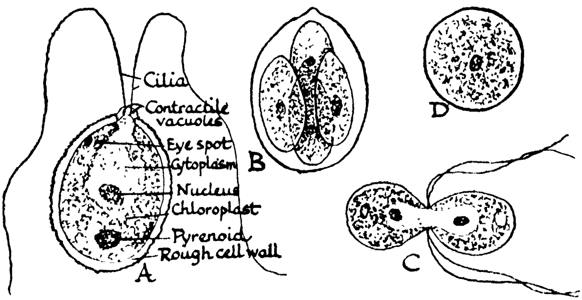

FIG. 7.—*CHLAMYDOMONAS*.

A. Single plant. × 50. B. Formation of zoospores.
C. Fusion of gametes. D. Zygote.

distance it swims, you will find that, in proportion, it moves much more rapidly than you can. Within the pointed end, just below the cilia, are two tiny contractile vacuoles, and it is suggested that the movements of the cytoplasm in expelling water from these vacuoles cause the movement of the cilia.

At the bottom of the basin-shaped chloroplast and within it, is a colourless food body called a pyrenoid, around which more reserve food is deposited. At one side of the chloroplast is a red spot, the "eye" spot, so called because of a very fanciful resemblance to an eye; there is no real resemblance.

FOOD AND FEEDING.

Every green plant is a chemical laboratory, in which comparatively simple substances are changed and combined together, and finally built into very complex substances. To form its cytoplasm and nucleus the plant needs certain substances, known as elements, because at present they cannot be resolved into simpler materials. Carbon is one of these; by adding other substances to it, it can be converted into compounds such as carbon dioxide. From this, oxygen may be removed and carbon regained; but up to the present time it has been impossible to take anything from carbon and leave a substance with different properties—that is, carbon is an element.

The chief elements found in protoplasm are carbon, hydrogen, oxygen, phosphorus, sulphur, nitrogen, and the metals calcium, potassium, magnesium and iron. If you learn the words represented by the letters, the order given is a very convenient one for remembering the non-metallic elements (C H O P S, N). All of these elements, except the three gases, are solids insoluble in water, so the plant cannot take them in as elements. The carbon it obtains in the form of the colourless gas, carbon dioxide, dissolved in the water, which itself is a compound of hydrogen and oxygen. The phosphorus, sulphur and nitrogen are combined with the metals and oxygen to form mineral salts such as calcium phosphate, magnesium sulphate, potassium nitrate and iron sulphate. Provided all the necessary elements be present in compounds which dissolve even very slightly in water, it will make no difference to the plant whether it has, for example, calcium nitrate, phosphate or sulphate. Actually it probably gets minute quantities of all three of these salts, dissolved in the water.

This unattractive diet of carbon dioxide, water and mineral salts is built up by the plant into protoplasm and food stores. In the chemical laboratory, heat, electricity and special apparatus would be necessary for such a complicated process. The *Chlamydomonas* has its special apparatus in the form of the chloroplast; light and heat are supplied by the sun, and the presence of electricity has been shown in some plants, and is probably in all. Sunlight and the green pigment, chlorophyll, contained in the chloroplast, are undoubtedly necessary for the plant to build up its food.

BREATHING.

When the fire is low and you want it to burn brightly, you force air through it with the bellows, or create a draught by any possible means. While the fire is burning, the heat energy given out may be used to produce electricity, to change water into steam or to do a variety of things. After the fire has burnt out ashes remain. The fuel has been changed to ashes and gases, mainly carbon dioxide.

There are, then, three outstanding facts to be observed when a fire burns:—

1. Air is necessary. It will be shown later that only the oxygen of the air is used.
2. Energy is produced.
3. The complex fuel is reduced to less complex substances.

This is exactly what takes place in breathing. The air dissolved in the water is taken in all over the surface of the *Chlamydomonas* and the oxygen combines with the complex food substances, or fuel, that the plant has built up. The energy gained from the sun to form these foods is now liberated and enables the plant to move and to carry on the other work of life. The foods are broken down into simpler substances which are waste, like the carbon dioxide and ashes from the fire. In fact, one of the waste products is carbon dioxide, and this passes out from the surface of the plant to the water. Day and night, every moment of its life, the *Chlamydomonas* breathes; that is, it uses oxygen to obtain the energy stored up in its food, and sends out carbon dioxide as a waste product. This may be summarised as follows:—

Feeding—Only in sunlight.

(Chlorophyll + Carbon dioxide + Water + Sun's energy) *give* (complex foods).

Breathing—Always.

(Complex foods + Oxygen) *give* (Energy + Carbon dioxide + other waste products)

This breathing process is the same in *Amœba*, for the animal feeds on the plant with its complex food and stored energy so that it merely has to use the oxygen to regain the energy for use in various ways. Carbon dioxide is sent out from the surface of the *Amœba*.

REPRODUCTION.

When the *Chlamydomonas* has plenty of food, and other conditions are favourable, the nucleus divides into two. These divide again, and the four nuclei usually divide once more into eight. Portions of the cytoplasm and chloroplast collect round each of the eight nuclei, and then a cell wall encloses each portion and eight small *Chlamydomonas* plants are formed inside the original cell wall, which breaks down and liberates them. They swim about, feed, grow, and develop an "eye" spot, just as the original parent did. Sometimes only four new plants are formed from one.

When such plants become less vigorous, or when unfavourable conditions occur, the *Chlamydomonas* will die unless it can protect itself in a suitable way. In the summer, water may evaporate rapidly, and then the dissolved food materials will be in a much more concentrated solution, which is harmful to the plant. Before this stage is reached, the *Chlamydomonas* divides, in the way just described, into eight parts. These parts look exactly like young *Chlamydomonas* plants, but differ from them in being unable to live unless they each fuse with a similar part from another plant. These parts are called gametes.

When the gametes have fused, a cell wall, thick enough to withstand heat and drought, is formed round the resulting cell, which is consequently able to rest until favourable conditions return. It then usually divides into four or eight new plants, which swim into the water after the protecting wall has broken down.

Paramœcium

You may find the *Paramœcium*, the "Slipper Animal", in stagnant water in ponds or ditches, or even at home if you have left cut flowers for some days without changing the water in the vase. You will be almost certain to find the animal

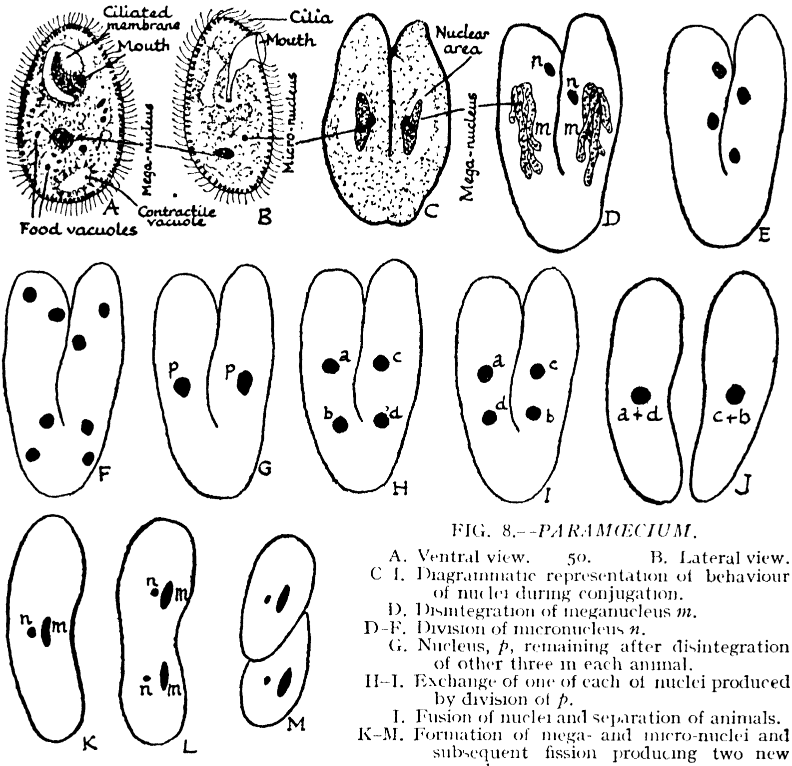

FIG. 8.—*PARAMŒCIUM.*

A. Ventral view. 50. B. Lateral view.
C–I. Diagrammatic representation of behaviour of nuclei during conjugation.
D. Disintegration of meganucleus *m*.
D–F. Division of micronucleus *n*.
G. Nucleus, *p*, remaining after disintegration of other three in each animal.
H–I. Exchange of one of each of nuclei produced by division of *p*.
I. Fusion of nuclei and separation of animals.
K–M. Formation of mega- and micro-nuclei and subsequent fission producing two new animals.

if you soak some hay or grass in water for about a week. The water will smell unpleasantly, and a slimy film will form on the surface. Both the smell and the film are due to minute organisms, called bacteria, on which the *Paramœcium* feeds.

Examine a drop of water under the microscope and look for an oval, colourless, unicellular animal, which swims about very rapidly. It can just be seen without a microscope.

The *Paramœcium* is unlike the *Amœba* in having a firm boundary; a tough coat which keeps it in shape, but allows it to bend easily. On one side the coat is indented to form a funnel leading obliquely into the cell. This funnel is the mouth of the animal. Protruding from the coat are numerous fine cilia arranged in longitudinal rows all over the surface. Within the funnel a few rows of these cilia are fused to form a very thin membrane, which waves about in the water.

Just inside the boundary, the cytoplasm is very clear and firm and embedded in it are short stiff hairs which can be thrust out between the cilia and may be of use to protect the *Paramœcium* from small enemies. The remainder of the cytoplasm is similar to that of the *Amœba* or the *Chlamydomonas*, but embedded in it are two nuclei: a large one, the meganucleus, and a smaller one, the micronucleus. Two large contractile vacuoles, one towards each end of the animal, appear and disappear alternately, so that when one is open the other is closed. Each receives waste liquid from a number of fine canals radiating into the cytoplasm. Many other small vacuoles are present.

MOVEMENT.

By the movement of the cilia the *Paramœcium* is propelled forward, while at the same time the membrane in the funnel waves to and fro and causes the animal to revolve, so that its movement is like that of a corkscrew entering a cork. Usually it moves with its broader end forward, but if necessary it can move with the pointed end foremost.

FEEDING.

By the action of the cilia and the membrane hanging from the funnel, small plants, plant fragments, and bacteria are washed into the mouth. The protective coat ends at the base of the funnel, and here the cytoplasm ingests the food, enclosing a minute drop of water with it, as in the *Amœba*. Digestive solution is made by the cytoplasm and forms a vacuole enclosing the food. This vacuole circulates round the animal, and during its travels the food particle becomes smaller and smaller as digestion proceeds. Finally, any waste matter is excreted when the vacuole reaches a position near the mouth.

BREATHING.

The *Paramœcium* resembles all other unicellular animals and plants in breathing all over its surface.

REPRODUCTION.

Like the *Amœba*, the *Paramœcium*, when it is living under good conditions and is very vigorous, divides by fission; and may do so every few hours. The meganucleus and the micronucleus divide each into two parts, which pass towards opposite ends of the animal. The cytoplasm gets narrower, obliquely, and finally two separate animals are formed. One animal has the mouth, the other has to make one.

When the animals seem to be losing vigour, two become attached by the oral surfaces (that is, the surfaces bearing the mouths) and conjugation takes place. The meganucleus of each breaks up and disappears, while the micronucleus divides into two parts which divide again. Three of the four parts disappear, and the fourth divides into two. The two *Paramœcia* now exchange a micronucleus and the animals separate, each containing one of its own micronuclei, and one from the other animal. The two nuclei fuse, and the resulting nucleus divides successively into two, until four nuclei are formed. The cytoplasm divides between the pair, and by oblique fission, two new *Paramœcia* are formed. Sometimes each pair of nuclei immediately divides again, and four new animals are produced. The surface of each grows in to form a mouth, the vacuoles appear, and the new animals soon begin to reproduce again by fission.

Under unfavourable conditions the cilia will be withdrawn, a thicker protective coat formed, and the animal encysts itself as *Amœba* does. It may then be blown about to fresh food supplies, and this accounts for its presence in an infusion of hay or grass and in stagnant water from cut flowers. The encysted animals were doubtless blown to the plants and were resting there until carried farther afield, or until the arrival of the water necessary for their active life.

So much of the description of a brick applies to the description of a whole wall. The additions consist in the way the bricks are laid and whether they have been differently moulded. This applies to a great extent to all living things, and the *Amœba* and the *Chlamydomonas* have been described here because cells similar to them are found in all animals and plants. The *Amœba* and the *Chlamydomonas*, each in its way, are leading what seems to be a satisfactory separate existence; then why should not all animals and plants consist only of a single cell?

In remote ages primitive man made his hunting weapons, caught his food, cooked it, made its skin into clothing and did everything for himself. His cooking would probably not have done credit to a chef, nor his clothing have been copied by a West End tailor—but how was it men became chefs and tailors? In the beginning, man probably associated with his fellows for protection against enemies too big for him to tackle alone. Then, perhaps, it was discovered that some men were better at hunting while others were better tailors, and so gradually, as men lived together, instead of living each for himself, each did what he could do best for the group, until in our present civilisation different men perform different services for the whole community and are often incapable of doing any other work efficiently. A good engineer would be a most extraordinary man if he were also a good tailor.

Plant and animal communities have most probably grown up in a very similar way. If an animal swallow a *Chlamydomonas*, that is undoubtedly the end of the plant. If, however instead of living in solitude, several *Chlamydomonas* cells joined together to make a bigger plant, there would be fewer chances of its being swallowed. Moreover, in such a colony of cells, if any cell were in a more favourable position for securing food it could share its advantage with the other cells. Actually there are several small water plants, some consisting of as many as twelve or sixteen cells, each exactly like *Chlamydomonas.* This is the simplest type of colony.

In the next stage the cells begin to differ slightly and to be set apart for different kinds of work. In a simple sponge, for example, there are cells which form the boundary of the animal, cells to create a water current to bring in food and air, and, lastly, cells like the *Amœba* which digest the food, reproduce the sponge, and do whatever other work remains to be done.

Finally, similar cells are grouped together in big masses for special work. Your brain consists of an infinitely large number of small cells which are quite different from the cells in your muscles or in your lungs. Your muscles may work exceedingly well, but they cannot think for you: your brain may be well developed, but it cannot do the work of your heart. Such specialised cells correspond to the engineer, the tailor, and other people who do special work for a community no one can do as efficiently the work of any other kind of specialist.

Spirogyra

As an example of a very simple cell colony we will examine another plant found floating as light green threads in ditches and ponds in the cooler parts of the year.

Each thread or filament consists of a number of brick-shaped cells placed end to end in a single row, which may be one or two inches long, and is usually less than one-hundredth of an inch in diameter. Every cell is exactly like its neighbour, and when young is filled with cytoplasm. As the cell wall grows, the cytoplasm grows much more slowly, so vacuoles are formed, and are filled with watery liquid. In each cell is a nucleus and a number of ribbon-like chloroplasts arranged to form a loose spiral just within the cytoplasm lining the cell wall.

The plant feeds and breathes in the same way as the

Chlamydomonas, and the food is stored in and around pyrenoids embedded in the chloroplasts.

Growth takes place by the division of the cells of the filament. The first nucleus divides into two and a wall is formed between them. The new cells feed, grow, and then divide again.

When the plant has grown sufficiently, the filaments float approximately parallel, and the cells of one send out short tubes which grow towards similar tubes produced by the cells of the other. When two of these tubes meet they fuse

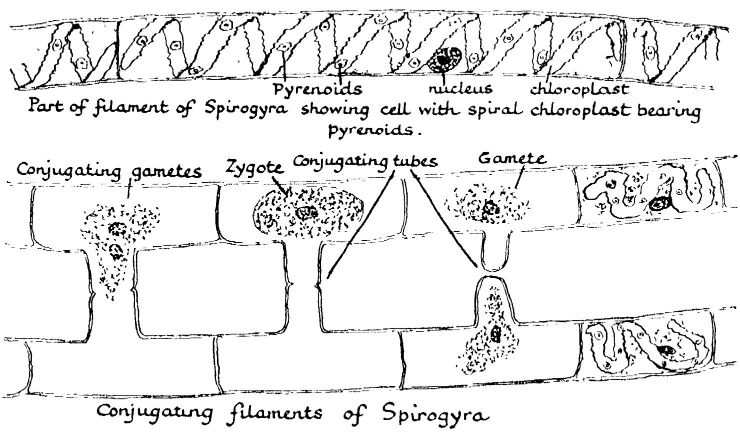

FIG. 9.—SPIROGYRA. × 70.

together, making a clear passage-way between the cells of the two plants (which now resemble the sides of a ladder with the connecting or conjugating tubes as rungs). Meanwhile the contents of each of the conjugating cells have formed a rounded mass called a gamete. The gametes of one plant squeeze in an amœboid manner through the conjugating tubes into the corresponding cells of the other plant. The two gametes in each cell fuse together, like those of *Chlamydomonas*, and form a zygospore (Gk. *jugon*, a yoke). This surrounds itself with a thick wall and rests for some time. It becomes dark greenish-brown, and has stored in it a certain amount of oil to supply food and energy for growth. When this takes place, the cell pushes its way through the thick coat, emerges clothed in a thin wall similar to the usual wall of the plant, and attaches itself by a pointed, colourless end to any convenient object. The cell divides, and, as growth proceeds, a new series of cells is formed, and the plant becomes detached and floats on the surface of the water.

Occasionally, when conditions are unfavourable to growth and to conjugation, the filament breaks up into a number of single cells, which surround themselves by a thick wall, rest until good conditions return, and then grow into new filaments.

The *Spirogyra* illustrates one of the simpler kinds of cell colony. Every cell does exactly the same kind of work as its neighbour, and the only advantages of living together are that if one or two cells be destroyed, the main body of the plant may continue to live and grow, and that total destruction is much less likely to happen to such a plant than to a single cell living alone. Moreover, any cell in a less favourable position than its neighbours for securing food may obtain some from them. A much more advanced type of colony will be found in the animal next described.

Hydra

Look under the weeds, especially duckweed, floating on the surface of a pond or ditch, and try to find a tiny green or brown or yellowish-white animal from one-eighth to half an inch long, and about as thick as a fine needle.

The name *Hydra* is the name of the group or genus, and, to distinguish the different kinds or species, a second name is given. Every plant and animal has thus its generic and its specific name. The generic name always begins with a capital letter and the specific name with a small one, except in comparatively few cases where the plant or animal is named after a person. If John and Bob Smith both have families, and people talk of the "Smiths", they make clear which they mean by saying "the John Smiths" or "the Bob Smiths". Bob Smith may have ten children; and, though they differ, they may all be distinguished from John Smith's children by his name. So every green *Hydra* is *Hydra viridis*, and every brown one, *Hydra fusca*; comparable to writing Smith, John, and Smith, Bob.

When you find the *Hydra*, take some of the weed and water with it. Put it in a glass jam-pot, and watch the animal move about.

Its body is shaped like a hollow cylinder, having usually at one end eight fine threads projecting. These are tentacles, and may be only six in number; or may be ten, or even more. The body and tentacles are both so flexible that the animal can turn somersaults, and when an enemy approaches, can contract itself to a small ball like a pinhead.

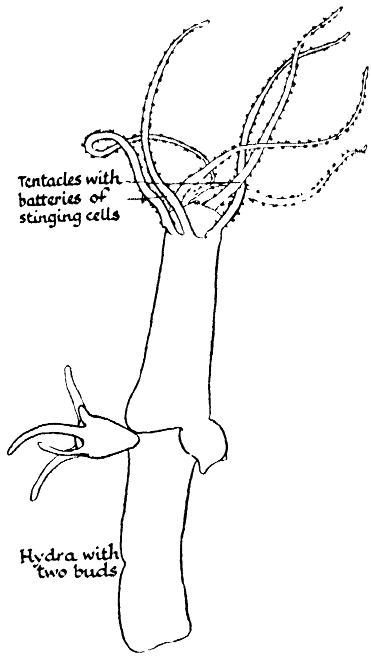

FIG. 10.—HYDRA, BUDDING. × 10.

When the animal is viewed as a whole under the microscope, in the centre of the tentacles an upright cone with a central opening, the mouth, can be seen. The opposite end of the animal is flat, and is called the foot. The *Hydra* usually moves with its tentacles hanging down in the water, and slides its foot along the lower surface of the water-weed by drawing up one side, arching the central part away from the leaf and then pushing the other side forward.

In moving by turning somersaults, the *Hydra* bends its body until its tentacles touch the leaf and then releases its foothold.

FOOD.

Water-fleas and other small animals are helped into the *Hydra's* ever-open mouth by the movement of the tentacles: but it is impossible to study the mode of feeding without first examining the cell structure.

Very little of the actual cells can be seen under the microscope without cutting sections. By a section is meant a very thin slice of the animal—thin enough to show the individual cells and their connection with their neighbours. A slice through the length of the animal is a longitudinal section; and a slice across, a transverse section.

Either section shows that the animal has two layers of cells, an outer boundary layer, the ectoderm (Gk. *ektos*, outer; *derma*, skin) and an inner layer, the endoderm. The two layers are held together by a clear gelatinous material, the mesoglea (Gk. *meso*, middle; *gloi*, glue).

The ectoderm consists of many different kinds of colourless cells. Most of them are slightly rounded and many have a thin, short outgrowth which passes downwards into the mesoglea and is capable of contracting and helping the *Hydra* to move. These may be called muscle cells; but, unlike the muscle cells of higher animals, they also help to form the boundary (or skin) of the animal. At intervals in the ectoderm, and especially on and near the tentacles, are groups of cells shaped like coconuts, each with an opening at the narrower end. The largest of these are stinging cells, and each contains a hollow dart about five times as long as the cell. Near the base of the dart are short stiff hairs, or barbs, pointing downwards. When the dart is withdrawn into the cell it is turned inside out and coiled like a spring. Near the opening of the cell is a fine projection, and any disturbance of this causes the dart to be shot out, just as the trigger of a gun causes the release of the bullet.

Within the cell, the dart is bathed in a fluid which is poisonous to tiny animals. When a small adventurer, such as the water-flea, swims near the *Hydra*, the trigger is disturbed, the dart shoots out, pierces the animal and injects the poison.

This paralyses or kills the prey, and the tentacles then waft it towards the "mouth". Even if the dart does not actually pierce the prey, the presence of the poison in the water is sufficient to paralyse very small animals.

Other similar ectodermal cells have rather shorter darts without any barbs, and these probably help to pass the prey towards the mouth, while the darts of others, found mostly on or near the "foot", attach themselves to different surfaces and help the *Hydra* to fix itself.

On the upper part of the animal are small irregular cells spoken of as "nerve cells", because they are believed to be especially sensitive.

The cells of the endoderm are very much like *Amœbæ*, and on this account are described as amœboid cells. There are, however, two important differences; each cell can protrude one, two, or three long fine hairs, the flagella, which move up and down, and promote the circulation of a water current inside the *Hydra*, drawing water into the mouth and sending it out again. The flagella may be withdrawn into the cell, which then exactly resembles an *Amœba* in form, but differs from it in being yellow or green.

In *Hydra fusca* the brown colour is due to the presence of a large number of tiny yellow unicellular plants, Algæ, living within each endodermal cell. *Hydra viridis* has many green Algæ as inmates of the endoderm, and the colour shows through the transparent ectoderm. The life history of these Algæ is very similar to that of *Chlamydomonas*, but since they are confined within the cells of the *Hydra* they have to obtain their food from these cells. Consequently, they take the carbon dioxide produced by the breathing of the animal, and build it into food. During this process oxygen is liberated and used by the *Hydra* and by the plants. The Algæ probably also use other materials formed by the animals as waste. At the same time the plants are protected from tiny animals which would eat them, and are carried about by the *Hydra* to fresh supplies of water which they would be unable to reach by themselves. The very young *Hydra* may live and grow for

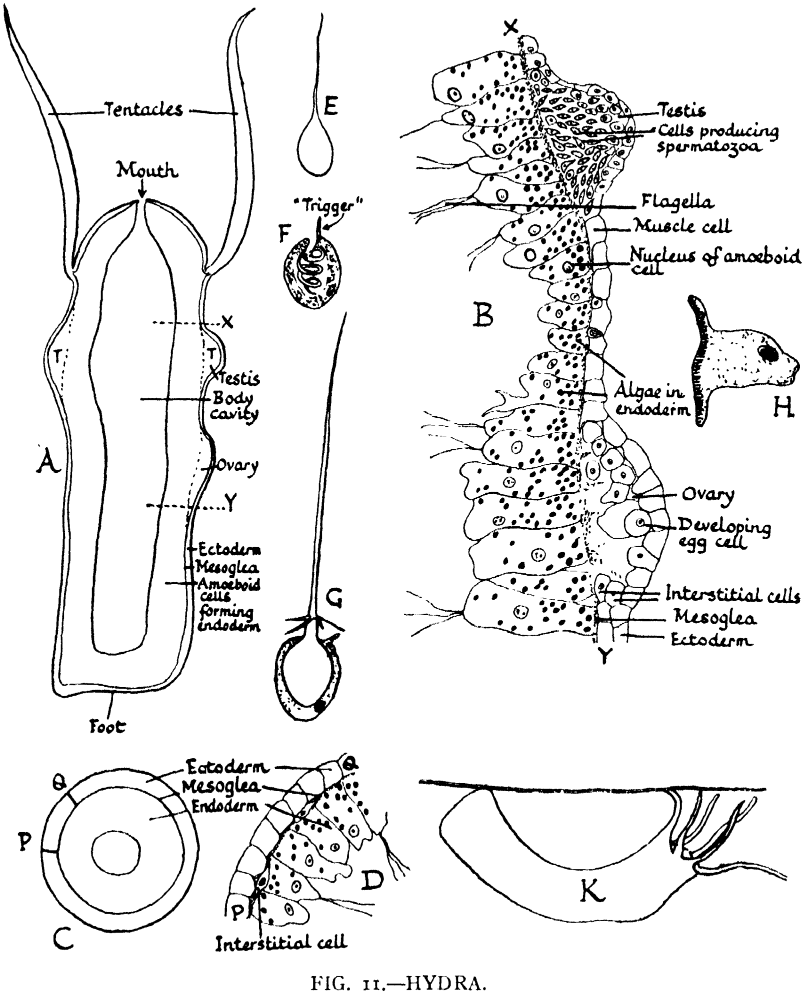

FIG. 11.—HYDRA.

A. Diagrammatic longitudinal median section.
B. Detailed structure of the part X Y of A. × 100.
C. Diagrammatic transverse section.
D. Detailed structure of part P Q of C. × 100.
E. Cell which helps to secure food.
F. Stinging cell with trigger and coiled dart.
G. Stinging cell with dart extruded.
H. Single muscle cell.
(E–H. × 500.)
K. Movement by somersaults.

a short time without the plants; but, if no Algæ co-operate with it, the animal dies.

Small rounded or irregular cells—the interstitial cells—lie in the gaps between the ectoderm and endoderm.

By the movement of the flagella, the food is sent through the mouth into the cavity of the *Hydra.* The endodermal cells, which are not engaged in creating the water currents thrust out pseudopodia, which enclose the food in the same way as the *Amœba* secures its meals. Within the cells the food is digested, and the solution is shared with the ectodermal cells. Animals too big to be seized by the digestive cells are gradually dissolved in the cavity; so the endodermal cells must secrete digestive fluid into the water. The cavity of the *Hydra* thus acts as a very simple form of stomach.

The cells excrete the harder, insoluble parts of the food into the cavity and this waste matter is carried out of the mouth by the water current.

You should notice here the difference between the meanings of the words "excrete" and "secrete". Both mean to send out; but *excrete* is used in connection with the giving out of *waste* matter; and *secrete* with the giving out of *useful* matter.

Any piece of the *Hydra* containing both endo- and ectodermal cells may grow into a complete animal. This is obviously not a natural method of reproduction, and is usually described as a regeneration of lost parts.

When conditions are suitable, one or more small protuberances formed by the outgrowth of the ectoderm and endoderm appear on the sides of the *Hydra.* These "buds" grow into tiny *Hydras,* and finally cells grow across the base of each and separate it from the parent.

Usually, in summer, other protuberances are formed on the surface of the *Hydra,* and are caused by special development of the interstitial cells. One cell of a group towards the foot sends pseudopodia round its neighbours and digests them, until it remains alone, very much enlarged and densely stored with food. Over this developing cell, known as the egg-cell, the ectodermal cells stretch tightly until they can no longer stand the strain. The ectoderm bursts and the egg-cell protrudes as a rounded mass, attached by its base to the *Hydra*. Towards the tentacles the interstitial cells divide rapidly, pushing out the ectoderm; and finally each tiny cell of the group divides into four parts called spermatozoa. Each spermatozoon consists of a nucleus with a small amount of cytoplasm round it, and a long cytoplasmic tail or flagellum.

A collection of animal cells producing one or more egg-cells is an ovary; a collection producing spermatozoa is a testis.

The spermatozoa are liberated by the splitting of the ectoderm, and swim about vigorously. When a spermatozoon reaches a mature egg-cell, the flagellum penetrates the cytoplasm, drawing the nucleus after it, and the two cells fuse completely. (Compare the fusion of two *Amœbæ* or of the gametes of *Chlamydomonas*.)

By the fusion, the egg-cell is *fertilised*; that is, it is rendered capable of growing into a new *Hydra*. An unfertilised egg-cell of this animal cannot develop; it decays, and is wasted, like the thousands of spermatozoa which fail to reach it.

Although a single *Hydra* may produce both ovaries and testes, the egg-cells and spermatozoa rarely mature at the same time, so cross-fertilisation occurs; that is, a spermatozoon of one *Hydra* fertilises the egg-cell of a different animal.

The fertilised egg-cell divides repeatedly until it forms a ball of cells. The outer ones secrete a substance which hardens to form a thick wall. Within this a thin wall is secreted, and the sphere drops into the water and rests for some weeks. (The parent *Hydra* usually dies after this method of reproduction.) At the end of the resting period the cells burst their protective coats, arrange themselves into ectoderm and endoderm walls and central cavity, and grow into a form like that of the parent *Hydra*.

Reproduction which depends on the fusion of two gametes is described as sexual reproduction. When the gametes are different, the egg-cell is regarded as female and the spermatozoon as male.

We have seen in the *Amœba* that there is no apparent difference in the two conjugating cells: and in this connection it is important to notice that both the cells are motile. In the *Hydra* there is a great difference between the reproductive cells, and only the spermatozoon is motile. This is usually the case with animals producing egg-cells with any considerable food supply, which retards the movement of the cell. The material of the spermatozoon is reduced to a minimum so that rapid movement is possible, and the amount of food is increased in the egg-cell to make adequate provision for the growth of the new animal.

In comparison with the number of egg-cells, enormous numbers of spermatozoa are produced, because they are so likely to be wasted. Many of them will be swallowed by water animals; many others will not find an egg-cell and will die of exhaustion. It is wonderful that a spermatozoon ever reaches an egg-cell, but partly on account of the large numbers produced and partly because the egg-cell attracts the spermatozoon, fertilisation is usually accomplished. Possibly the attraction is due to the food contents of the egg-cell; or it may secrete an attractive substance into the surrounding water.

Animals and plants in which an individual can produce both male and female cells are hermaphrodite; those producing only one kind of reproductive cell are described as male or female, according to the kind of cell they produce.

FERTILIS .TION.

Most animals and plants are capable of reproducing by means of fertilised egg-cells. Usually, *cross*-fertilisation takes place, but sometimes both the egg-cell and the cell fertilising it are produced by the same animal or plant. In this case, *self*-fertilisation occurs. When the parent is vigorous, the young ones resulting from self-fertilisation are likely to be quite strong and healthy, but when the parent is weakly, the young ones may be unhealthy and may eventually die out. This is less likely to occur in cross-fertilisation, as there is less probability of both parents having the same weaknesses. Moreover, if one parent differs in any striking way from the average, the other is not likely to differ in the same way, and so cross-fertilisation is more likely to result in the production of individuals having fewer outstanding peculiarities.

PRACTICAL WORK

1. Place a drop of water, containing some *Amœbæ*, on a glass slide and cover with a thin glass slip. Watch the animal and draw as much of its structure as you can see.

In the same way examine and draw:—

2. *Chlamydomonas*.

3. *Paramœcium*.

4. *Hydra*.

5. If you have a sufficiently powerful microscope, add a drop of water containing *Paramœcium* to a drop of dilute iodine solution on a glass slide. Place a cover-slip over the drop and try to find the nuclei of the animal. The iodine stains the cytoplasm light brown and the nucleus dark brown. (You will not find the micronucleus unless the magnification is much higher than is commonly used.)

QUESTIONS

1. Describe the way in which two kinds of water animals protect themselves during drought.

2. Make a list of the elements the plant needs for food. In what forms are these obtained?

3. What conditions enable a green plant to use carbon dioxide?

4. What are the advantages and disadvantages, if any, of a cell wall to a unicellular animal or plant?

5. Describe the way in which the *Hydra* secures its food.

6. How is the zygospore of *Spirogyra* formed? Describe its subsequent development.

7. What is breathing? To what would you compare it, and why?

8. Why do animals and plants need oxygen?

9. Is it correct to say that carbon dioxide is excreted? Justify your answer.

10. What is meant by an amœboid cell and by amœboid movement? Name plants and animals in which examples of either are found.

11. Distinguish between ingestion and digestion.

12. Describe three kinds of cells fitted for special work.

13. Name some cells which secrete fluid and say in each case what use is made of the secretion.

14. What does a living creature gain or lose by having special cells for different kinds of work?

15. Describe the gametes of *Chlamydomonas*, *Spirogyra*, and *Hydra*.

16. How does the conjugation of *Amœbæ* differ from that of *Paramœcia*?

17. What do you understand by conjugation? Name plants and animals which reproduce by this method.

18. State the advantages in the production of very unequal gametes, such as those of *Hydra*.

19. What is meant by cross-fertilisation? What advantages may it have over self-fertilisation?

CHAPTER IV

HOW TO STUDY AN ANIMAL

The Cat

To study any living creature we must first observe accurately, and then be able to state our observations clearly, so that our meaning cannot be mistaken. For instance, people speaking of the cat's back sometimes mean the tail end of the animal and sometimes the part away from the ground. In order that the part which is being spoken of shall be unmistakable, the tail end is described as the posterior, and the head end the anterior, end, while the part which is usually away from the ground is dorsal, and that nearer to it ventral. Man is the only mammal that habitually walks with only two feet on the ground. If you crawl on "all fours", pretending to be a lion or a tiger, you are in an attitude similar to the usual one of such animals, and it is obvious that your back is dorsal and the front of your trunk ventral.

In animals, such as the *Paramœcium,* which have neither head nor tail, the end which usually moves forward is anterior, and the opposite end posterior. Whenever possible, these terms are used, but you should be able to think why they cannot be applied to some lower animals such as *Amœba* and *Hydra.*

In studying the cat you will find it much more helpful if you first examine the animal and note all you can find out about it. Drawing is especially helpful to accurate observation and to memory.

HABITAT.

The cat, as we know it, has been domesticated for hundreds of years, but it is closely related to the wild cat which still exists in Egypt, Europe, and Asia, and lived in Great Britain until about the beginning of the nineteenth century. Centuries before the birth of Christ there were domestic cats in Egypt, and these were probably introduced into Greece, and later into Rome. It is probable that the Romans brought

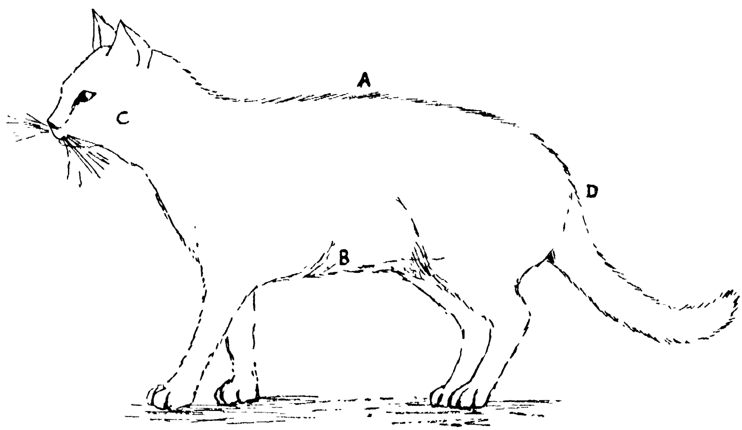

FIG. 12.—CAT, SHOWING—

A. Dorsal surface. B. Ventral surface. C. Anterior end. D. Posterior end.

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domestic cats into England, where they have become very well established. The habitation of man in temperate and hot climates has become the habitat of the domestic cat.

APPEARANCE AND EXTERNAL STRUCTURE.

The wild cat is very savage and is larger than the domestic cat. Its tail is shorter and thicker, and its fur is always marked like the tabby cat's. Except for a few other small differences, the following description of the domestic cat will apply to the wild cat.

Cats vary considerably in size and colour. The commonest type is the tabby cat, but black, sandy, white and bluish-grey cats, and cats with various markings of these colours are all quite common. Tabby cats and many of the other cats with markings have lighter coloured fur on the ventral surface. This is a special characteristic of the wild cat, and makes it less conspicuous. If you look at a log of wood lying on the ground in the sun you will see that the part toward the sun is light, and the part away from the sun is in shadow. This effect of light and shade makes the log easily seen as a solid object. Now imagine the wild tabby cat in the forest. The light filtering through the trees falls on the dark dorsal surface and makes it lighter. The light ventral surface is in the shadow, and appears rather darker, so that the two surfaces now seem to be uniformly coloured, and the cat appears to be a flat patch on the ground. The darker stripes seem to break this flat object into smaller earth-coloured areas, so that, when the cat is still, it is not easily distinguished by its enemies nor by its prey. You will find that most wild animals of all classes have this protective colouring, but many domesticated animals, such as black or white cats, pet rabbits and mice, have been protected by man and so have survived in spite of being conspicuous.

The cat is covered with soft, glossy hair, which is much shorter on its face and paws than on the rest of the body. Generally speaking, soft, glossy hair is called fur, but it is impossible definitely to distinguish hair from fur. Just as your old hair falls out gradually and new hair grows, so more of the cat's hair falls out in spring and its coat is thinnest in summer, while new hair grows to make the coat thickest in winter. When the cat is angry or afraid, as when it meets a dog, its hairs are pulled upright by tiny muscles beneath the skin, but when the cat is not disturbed most hairs point backwards to the posterior end. There are no hairs round its nostrils nor on the pads of the paws. The cat would not get a sure foothold if its paws were entirely covered with fur, nor would it be able to raise its feet so quickly, and on rough surfaces the hairs would be torn out.

A short neck joins the trunk to the head and raises it to its usual position above the general body level. Compare the neck and head of the cat with that of the pig or rabbit and you will see that the latter have even shorter necks, their heads are much more pointed and can be raised very little above trunk level, except when the animal rises on its hind legs; their eyes are on the sides of the head, their ears are longer. Now think how these differences fit the animals for the lives they lead. The cat left to get its own food often catches birds. Its neck enables it to look up to the tree-tops, and the position and structure of its eyes enable it to see clearly objects far and near.

The rabbit has practically no neck, and can turn its head very little to see or hear anything behind it, but the rabbit does not need much neck to help it to get its food, and a neck would be a disadvantage in a burrow. Think how often the rabbit would knock its head against the sides and roof! So the disadvantages due to a short neck are removed by the position of the eyes at the sides of the head, and the very long, flexible ears, which can be turned in any direction to collect the sound. Since the cat can turn its head easily it does not need such long, flexible ears as the rabbit.

The cat's head is not as wide as its trunk. How is it, then, that if a cat be able to put its head through a hole it will be able to get its whole body through? Measure the breadths of the head and trunk of the cat, and then measure from the tip of the longest whisker on one side to the tip on the other. This total breadth is greater than that of the trunk, and since the whiskers are very sensitive, by the way they touch the sides of an opening the cat can judge whether it will be able to squeeze through. The tips of the ears, too, are extremely sensitive, and may help the cat to judge the height of an opening.

It is often stated that cats can see better in the dark than in the light, but there seems to be no foundation for this statement. If you slept during the day and had to get your meals in darkness you would soon begin to see much more without the aid of artificial light than you do now. Before man protected and fed it, the cat hid in the forests from its enemies during the day and hunted its food at night, so that it accustomed its eyes to use in the semi-darkness. Also there is in the eye a special structure which probably enables it to make the greatest use of the available light, and to see better at night than we can. The domestic cat still prowls at night if allowed to do so, and uses its eyes as it does in the day. When light is scarce, the coloured part or iris of the eye is drawn back by muscles to form a large circular opening, the pupil, but in bright light the iris is nearly closed, reducing the pupil to a narrow, vertical slit. The cat's eyes are protected by an upper and lower eyelid and by a membrane forming an inner eyelid which is attached at the inner corner of the eye, and can be drawn partly across it to shield it, or to remove dust.

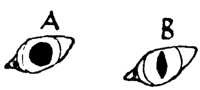


FIG. 13.—EYE OF CAT SHOWING SHAPE OF PUPIL. × ½.

A. In darkness.
B. In bright light.

The nostrils are rounded openings very close together, and if you have noticed the behaviour of a cat when fish is concealed in the house you must have discovered that the animal has a keen sense of smell. It seems curious that unless the cat watches you put a piece of fish or other food on the ground, it often cannot go directly to the food, but moves its head above, smelling round about and seeming unable to find it for some seconds. This is probably because its eyes are situated well up on the head, so that it can see objects beneath only when it bends its head right down. If you shut your eyes and try to find an apple merely by smelling you will get near the apple, but you cannot get directly to it unless you use your sense of sight or of touch. Similarly, the sense of smell will lead the cat to the neighbourhood of its food, and then the sense of sight must be used to help the animal to secure it.

At the base of the head is the mouth, a wide **V**-shaped opening, with very thin lips. On either side, even when the mouth is closed, one tooth can usually be seen projecting slightly.

When you feel the trunk of the cat carefully you can feel at the anterior end a bony framework made by the ribs. These mark the region of the thorax, and posterior to this is the abdomen.

Examine and measure the legs and feet of the cat and count the toes.

Before discussing the differences between the fore and hind legs let us consider what they have to do. Of course they move the cat, but why has it to move? Before the cat became a domestic animal it had to hunt for its food, to escape from enemies, or to fight them, and to seek shelter from the weather. To gain shelter, any kind of movement might do, but the cat could best secure its food by moving stealthily and by using great agility in springing on its prey. To escape from enemies it needed swiftness, and, to fight them, weapons such as teeth and claws were invaluable.

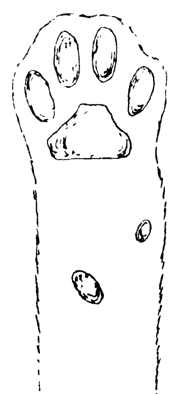


FIG. 14.—RIGHT FORE PAW OF CAT. × ½.

The soft pads ensure the stealthy movements, the agility is due to the muscles and skeleton, and by examining the limbs you may see how the swiftness and the springing movement are possible. When you run swiftly, you run on your toes without stopping to put your whole foot down. The cat always moves on its toes, and its heel and the remainder of the foot are raised above the ground and covered with fur. The heels on the hind legs can be seen very well as the heel bone projects considerably at the back. The fore feet are shorter and the "heel" (which really corresponds to our wrist) does not project so much, but the joint can be felt easily. Thus the cat's feet are adapted for swiftness. When the animal is going to spring, it crouches down, resting the whole of each foot on the ground. Then it raises the heels, pressing on the toes, so using the feet, especially the longer hind ones, each as a lever, or a springboard, and pushes itself forward on its prey. You will get some idea of the strength of the movement by holding a ruler upright by fixing its base firmly between your thumb and the edge of your desk. Pull the top of the ruler slightly toward you and then release it, and watch the rebound.

In the fore legs, a short distance above the wrist joint, you can feel another joint that corresponds to our elbow, and in the hind legs, close to the body, is the knee joint. The greater length of the hind legs helps the cat to leap farther than it could if its legs were of the same length.

The weapons for attack and defence, and the implements for holding its food, are the claws, five on the fore paws and four on the hind ones. The inside claw on each of the fore feet is higher up on the paw than the others, because the digit is shorter. This digit corresponds to our thumb, and is entirely missing from the hind paws. When the claws are not in use they can be drawn up into a sheath of skin to protect them from being blunted or broken, and are drawn down again when they are needed. The movements are similar to raising and lowering a drawbridge or the lid of a desk.

The cat's tail is usually fairly long, except in Manx cats, which have none. Its only uses seem to be to aid balance and to show whether the cat is pleased or angry.

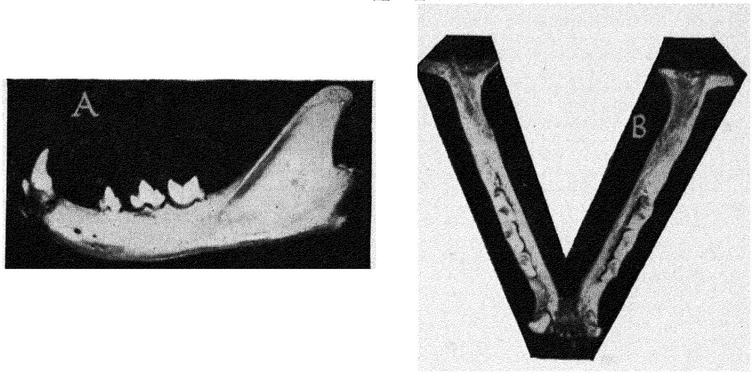
Food.

When the cat has to get its own food it drinks water, catches birds, mice, and other small animals, and grasps its prey firmly with the curved claws.

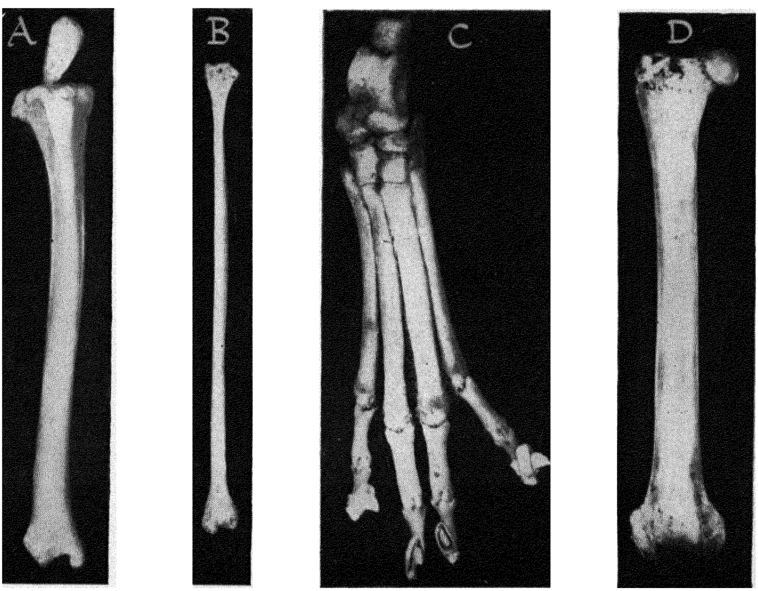
Teeth.

The food then has to be torn and prepared for swallowing, and three kinds of teeth assist in this preparation. In the front of each jaw are six small chisel-shaped cutting teeth, the incisors (L. *in*, into; *cædere*, to cut), and on either side of these projects a single long, pointed tooth, which is also well developed in the dog, and so named after it the canine tooth (L. *canis*, a dog). The canines are prominent in all

PLATE II



A. Left lower jaw of cat showing molars and canine tooth.
B. Lower jaw of cat showing molars canines, and incisors.



HIND LEG OF CAT.

A. Tibia with patella (knee-cap) attached.
B. Fibula.
C. Hind foot with one toe turned aside to show socket for claw.
D. Femur. Note the ball-shaped head which fits into the cup-shaped socket in the pelvic girdle.

flesh-eating, or carnivorous mammals, and are used for tearing the meat. The remaining teeth grind the food, and are the molars (L. *mola*, a mill). These have two roots or fangs, but the other teeth have only one.

Like man and most other mammals, the cat has two sets of teeth. Some of the first set, or milk teeth, may appear before the kitten is a week old, and usually the twenty-six milk teeth have grown through by the end of the first six weeks. In the top jaw next the canines are three pre-molars; in the bottom jaw there are only two. The true molars grow later, one on either side in each jaw, and belong to the permanent set. The milk pre-molars are replaced by permanent ones. They have broad crowns with a large central pointed protuberance and two small rounded ones behind this. The true molars have two large pointed protuberances. The lower teeth bite slightly in front, and between these protuberances those of the upper ones fit to cut and grind the food. The first pre-molar on either side of the top jaw has no lower tooth to meet it, and so is of little use.

Between the incisors and canines is a gap which allows the food to be torn freely.

The permanent teeth generally appear when the cat is from five to seven months old, and in growing usually push out the milk teeth.

Round the root of each tooth is a rough bony substance, the cement, which fixes the tooth firmly into a socket in the jaw-bone. The crown of the tooth is covered with enamel, the hardest material found in the body, and well fitted for the difficult work the teeth do. When the enamel wears away, a much softer substance called dentine is exposed. This is porous and may allow liquids to pass through to the centre of the tooth, into the pulp cavity containing the nerves and blood vessels which pass in through a tiny channel in the dentine of each root. If the nerve be affected by pressure, liquid, or change of temperature, pain will be caused. It is difficult to find out whether the cat suffers from toothache, but it almost certainly does if its teeth decay.

DIGESTION.

The whole digestive system is a series of chemical laboratories where highly specialised work goes on. When the work in one laboratory has been carried as far as possible in the time allowed, the food passes on to the next, and then on again until no more work on it can be done.

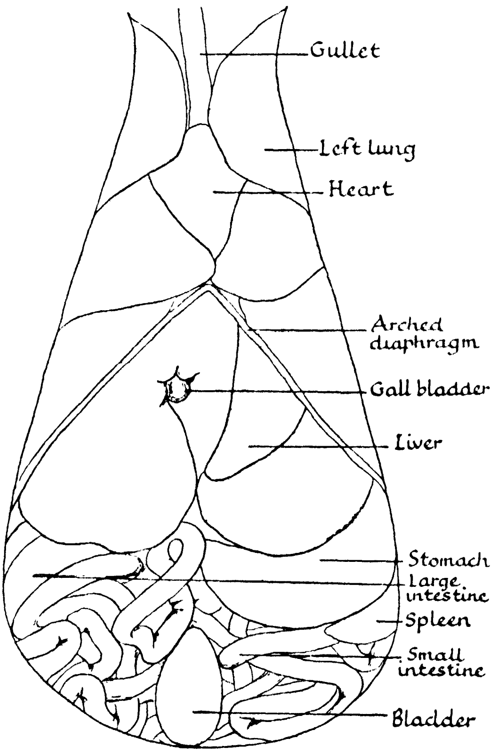


FIG. 15.—VENTRAL VIEW OF INTERNAL ORGANS OF CAT. × ½.

The mouth is the first laboratory, and receives a watery liquid, the saliva, which is alkaline, and can change the insoluble starch in the food material into soluble sugar. Under the tongue and at the sides of the mouth are several salivary glands, each consisting of a collection of cells which extract substances from the blood to manufacture the saliva.

This is then secreted by the cells, and conveyed to the mouth by a main tube or duct from each gland.

By the tongue the food is pushed between the teeth, which masticate it well, so that the saliva can act on as large a surface as possible. You may realise the importance of thorough mastication by taking two equal lumps of washing soda. Crush one to powder and add an equal amount of water to each. You will find that if both are subsequently treated in the same way, the powdered soda will dissolve much more quickly than the lump. Similarly, if the teeth reduce the food to tiny pieces, solution or digestion will proceed much more rapidly.

The tongue collects the masticated food into a ball and pushes it to the entrance of the next laboratory. This entrance, the pharynx, is a funnel-shaped muscular structure at the back of the mouth, and leads into a long, tubular corridor, the gullet, which passes through the thorax and pierces the diaphragm. The muscle cells in the wall of the pharynx and gullet contract behind the food and push it on, in much the same way as a boy shoots out a pea or piece of chalk by pressing his thumb and finger behind it.

Though the diameter of the gullet and its moist walls prevent the food from moving as rapidly as the pea, it soon reaches the stomach, which is a comparatively large bag with a wall made of layers of muscle cells. The cells of these layers contract in different directions: some cells make the stomach long or short, others make it wide or narrow, while others run obliquely, and by the combined movements of all three sets the food is pushed about and turned over so that it can be well mixed with the gastric juice, the solvent used in this laboratory. This juice is a very watery fluid secreted by some of the cells lining the stomach, and contains a small amount of acid which neutralises the alkaline saliva, so that further action on the starch is prevented. Pepsin is also contained in the juice, and changes the complex nitrogen-containing foods, the proteids, into simpler substances called peptones, which can be more readily dissolved. The temperature of

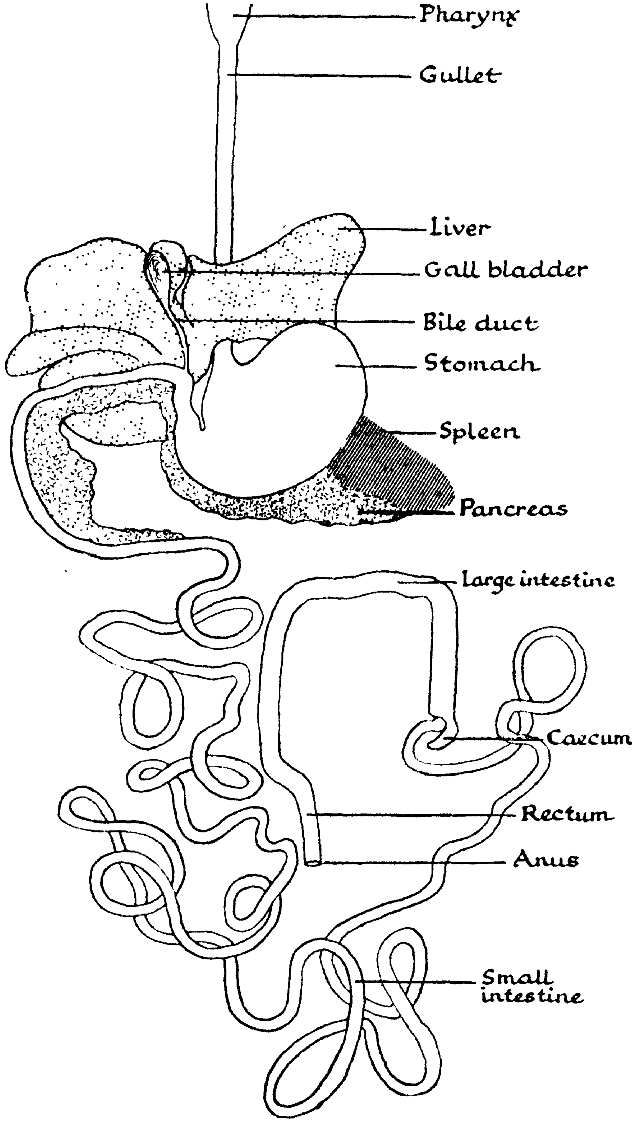


FIG. 16.—DIGESTIVE SYSTEM OF CAT. × ½.

this laboratory, and the churning action, are sufficient to melt fats and to separate them into small particles.

At intervals small quantities of food are now squeezed from the narrow end of the stomach through a muscular opening into the next laboratory, a tube about two feet long and a quarter of an inch wide. This tube is the small intestine, and receives juices from two glands, the liver and the pancreas. The largest gland in the body is the liver, which lies beneath the diaphragm, and arches over the stomach. It is dark purplish red, divided into five lobes, and covered with a thin, smooth skin. The cells of this gland manufacture a green alkaline liquid, bile, and secrete it into minute ducts, conveying it to a main duct opening into the gall bladder, where the bile is stored until needed.

The pancreas or "sweetbread" is another gland, rather flat and long, situated in the bend between the stomach and beginning of the small intestine. The cells of the pancreas make and secrete a watery juice and send it through ducts into the intestine.

The bile and pancreatic juice enter the small intestine together. The acid from the stomach is neutralised, and the alkaline juices, acting on the starch, finish changing it into sugar. The solution of the proteids is continued and the dissolved sugar and proteids are absorbed by the cells lining the intestine and passed directly into the blood vessels. The digestion is helped by juices secreted by some of the cells lining the small intestine. The alkali in the bile converts the fats into glycerin and tiny globules of soap. Such globules suspended in liquid are spoken of as an emulsion, and in this form the digested fats are absorbed into special vessels and conveyed in a colourless fluid, the lymph, to the left side of the neck, and there passed into a blood vessel.

Thus, in its passage through the small intestine the food becomes less and less, and the remainder passes into the last laboratory of the series—the large intestine, so called because, although it is less than a quarter the length of the small intestine, it is about one and a half times as wide. At the junction of the two intestines is a small tubular outgrowth, the cæcum. As the food passes on, the remaining proteids are dissolved and food solutions are absorbed. Any solid matter reaching the end of the large intestine is waste, because there are no more laboratories in which it might be dissolved. The waste collects in the excretory tube or rectum, and is excreted from an opening, the anus.

The pepsin and also the substances in the pancreatic juice which change the proteids into soluble substances are called ferments or enzymes (Gk. *en*, in; *zume*, leaven). Enzymes were first discovered in yeast, or leaven as it used to be called. They are substances produced only by living cells, and are able to effect chemical changes, though they themselves remain unchanged at the end of the process. In yeast, for example, there is an enzyme known as *zymase*, and this ferments sugar in solution, converting it mainly into alcohol and carbon dioxide. When fermentation ceases, the zymase remains unchanged. Other enzymes are present in the saliva and pancreatic juice and effect the change of the starch into sugar.

Attached to the left dorsal side of the stomach is a long, dark red, flattened body, the spleen. This is not directly a part of the digestive system, though it probably helps to begin the manufacture of the colouring matter of the bile.

The digested food has to be conveyed all over the body for the use of cells doing other special work. This distribution is effected by means of a pump and pipes in much the same way as water is distributed to the different houses in a town.

CIRCULATION.

The pump, or heart, lies half way down the thorax, and is partly enclosed by the lungs. The narrow end, the apex, points very slightly to the left side, and is just beneath the ribs. The base, which is directed towards the head, is about three-quarters of an inch wide, and the length is about an inch.

A smooth thin skin covers the dull red muscular wall of the heart, grows round the roots of the blood vessels, and then turns back, forming an outer skin bag. Enclosed in this bag, the pericardium (Gk. *peri*, around; *kardia*, heart) is a little fluid which helps the muscle cells to work—like the oil in a pump—and which also helps to protect the heart. On each side of the broad base is a fleshy lobe called, on account of its shape, the auricular appendage (L. *auris*, ear).

The heart is completely divided into left and right sides.[1] Each side is divided into a small upper chamber, the auricle, and a larger lower one, the ventricle. Like every efficient pump, the heart is provided with valves, which allow the liquid to pass in one direction only. These valves are trap-doors between the auricles and ventricles.

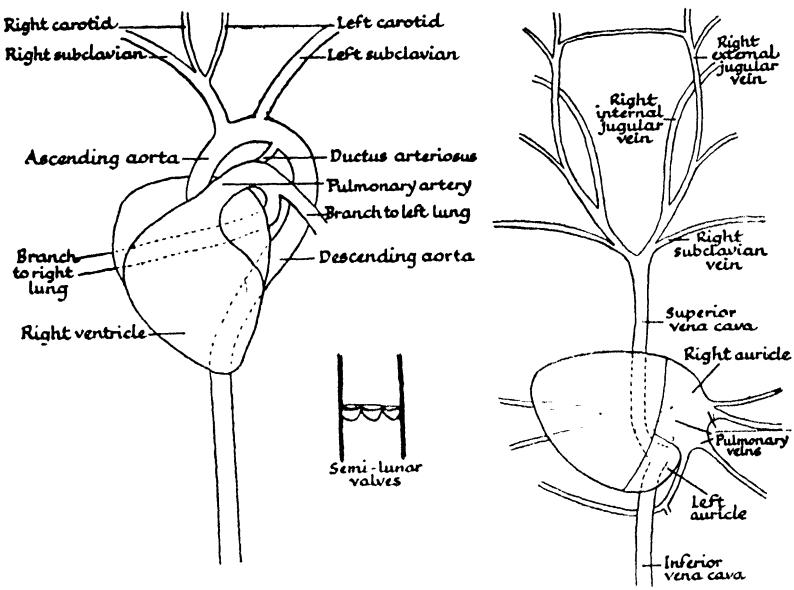
The blood is an almost colourless, watery liquid, containing dissolved food and numerous minute bodies called corpuscles (L. *corpus*, body). These are of two kinds, the red and the white. In structure the white corpuscles are like the *Amœba*, moving in the same way, ingesting bacteria or any foreign substances which may have entered the blood, and carrying them out of circulation. The red corpuscles are smaller, much more numerous, and give the blood its colour. They are circular, have no nucleus, and though unable to change their outline, are so flexible that they can bend and squeeze their way through the narrowest capillaries. The red colouring matter in the corpuscles carries the oxygen and gives it up to the body cells.

The distributing pipes are of three kinds, arteries, veins, and capillaries. Arteries convey blood *away from*, veins convey it *to*, the heart. Capillaries (L. *capillus*, a hair) are very fine thin-walled tubes connecting arteries and veins.

A large vein, the superior vena cava, collects the impure blood from the anterior part of the body, while the inferior vena cava collects it from the posterior part. The two veins join at the entrance to the right auricle and pour into it the impure blood. At the same time four veins, the pulmonary

[1] The left side of the heart is on the left of the cat, although it may be drawn on the right of a diagram. Diagrams often show the animal opened from its ventral surface, and when you look down at a cat lying on its back the left side of its heart is on your right.

veins, pour pure blood from the lungs into the left auricle. The blood flows in until ventricles and auricles are full. The muscular walls of the auricles now contract and squeeze the blood into the ventricles, where it gets behind the tough skin of the valves and pushes them up, closing the opening between the auricles and ventricles. The ventricles have thicker muscles than the auricles because they have harder work to do.



Arteries. $\times \frac{3}{4}$. Veins. $\times \frac{3}{4}$.

FIG. 17.—HEART AND MAIN BLOOD VESSELS OF CAT.

They have to force the blood through comparatively small openings into arteries. On the right side the impure blood is squeezed into the pulmonary artery leading to the lungs, and from the left ventricle the pure blood is forced into the aorta, which distributes the pure blood all over the body. The blood vessels have muscular walls, and would tend to squeeze the blood back, especially when the ventricles are empty. To prevent this backward flow there are at the roots of the vessels three crescentic pockets of skin, the semi-lunar valves, into which the blood flows, filling them out so that they close the exit from each ventricle.

The auricles fill and empty so quickly that there is no obvious pause between the contraction of the auricles and ventricles, but the contraction passes like a wave from the base to the apex of the heart, and each fresh quantity of blood forced into the arteries causes a wave or pulse which can be felt when an artery is pressed against a bone.

The diagrams show the heart, main blood vessels, and the other internal organs of a kitten five days old. Between the aorta and pulmonary artery is a tiny connecting vessel which is of use in the development of the young animal, but the vessel is closed a week or two after birth. For a very short distance the aorta runs from the left ventricle towards the head, then curves back, passes dorsal to the heart, and runs the whole length of the body, sending branches to the liver, kidneys, and all other parts of the abdomen. Finally the aorta divides into two branches, one entering each hind leg.

From the anterior or ascending aorta, branches pass to the head and fore legs. The carotid arteries supply the brain, the jugular arteries the face and scalp, and the subclavian arteries the fore legs.

All these arteries branch repeatedly, and their branches become finer and finer until they at last become capillaries. In the walls of the heart, and of the digestive system, in the lungs, the brain, the muscles of the limbs and head—in fact, in every part of the body—these capillaries are to be found. Through their thin walls food and oxygen pass from the blood into the cells, and in return the waste products formed by the feeding and breathing of each cell pass into the blood. The process is almost exactly similar to that described in *Chlamydomonas*. Thus in passing through the capillaries, with the exception of certain ones in the lungs, kidneys, and skin, the blood becomes more and more impure and darker in colour as the waste carbon products pass into it. It is forced into small veins which join to form bigger ones, until at last the branches lead into the inferior or superior vena cava, and so the impure blood is taken to the right side of the heart. Get a piece of glass tubing drawn out to a capillary tube in the middle, so that it is wide at both ends. Fill one of the ends with water and watch the behaviour of the water when it reaches the capillary tube. If the bore be fine enough, the water will not flow into the capillary, but you may force it in by blowing through the tube. When you stop blowing the flow stops, and if you fill the capillary and start forcing the water through into the other wide end you will see how slowly the flow proceeds. This will give you some idea of the way in which the blood is forced by the heart into the arteries and capillaries, and the slow oozing from the capillaries into the veins. Because of this decreased pressure in the veins there is a tendency for the blood to flow back. To prevent this, every vein has semi-lunar valves at short distances throughout its course.

You can show the presence of these valves in your own veins by firmly stroking the more prominent veins of your hands or arms towards the finger-tips to press back the blood returning to the heart. The valves become filled with blood and form knotted swellings.

THE KIDNEYS.

The water mains convey water to the different houses for use, and the used water has to be conveyed from the houses and from the town by drains. So, in the body, the blood is carried round for the use of the different cells and they make it impure. The kidneys, and tubes leading from them, act to some extent like the drains, but the impure blood is specially filtered, and only a part of it is conveyed right out of the body.

The kidneys are two bean-shaped bodies lying in the abdomen on either side close to the backbone and ventral to it. A branch from the descending aorta enters each kidney, and the capillaries send food to the cells, and send out a solution of certain waste substances, chiefly urea, which have been dissolved in the blood. This solution passes into minute tubes opening into a funnel-shaped cavity in the kidney. From this cavity the liquid is conveyed by the ureter, a narrow tube entering the bladder, a very muscular bag where the urine is stored until sufficient has been collected to be excreted. By the contraction of the muscles it is then expelled from the body through a tube called the urethra. The blood, from which this waste has been removed, passes into veins, which join to form a main one leading into the inferior vena cava. Here, then, is an example in which blood becomes purer during its passage through capillaries: other examples are to be found in the lungs and skin.

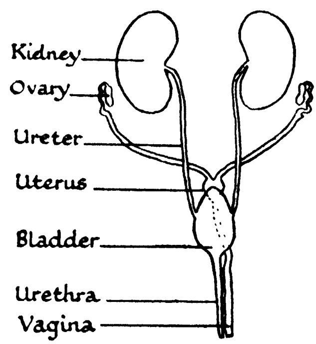


FIG. 18.—KIDNEYS AND ORGANS OF REPRODUCTION OF FEMALE KITTEN. × ½.

BREATHING.

The kidneys cannot remove all the impurities because some of the waste carbon products do not dissolve in the blood, but are held by the colouring matter of the corpuscles, making it a much darker red. It is the work of the lungs to restore the bright red colour by removing this waste.

The cat has two large lungs which fill the thorax except for the small space occupied by the heart and gullet. The lungs are divided into lobes, three on each side and one median one, and all the surfaces are covered by a very smooth skin, like that lining the thorax. Between the lungs and the wall of the thorax is a small quantity of colourless fluid to act as a lubricant.

Air enters the lungs through the windpipe or trachea, which in the neck lies ventral to the gullet. When the gullet is not in use it becomes flattened, but the windpipe never becomes flattened because it is stiffened by circular bands of firm white material, the cartilage. At the entrance to the windpipe is a wider cartilaginous part called the larynx, and this has at the opening a triangular flap of cartilage, the epiglottis, which closes the entrance while food is being swallowed. If you throw back your head and run your finger down the middle of the front of your neck you may feel the cartilaginous rings of the windpipe, and the beginning of the larynx just beneath your chin. If people talk while eating, the air will force the epiglottis open, food may enter the windpipe and disaster follow. The consequent coughing is a violent expulsion of the air from the lungs in an attempt to clear the trachea.

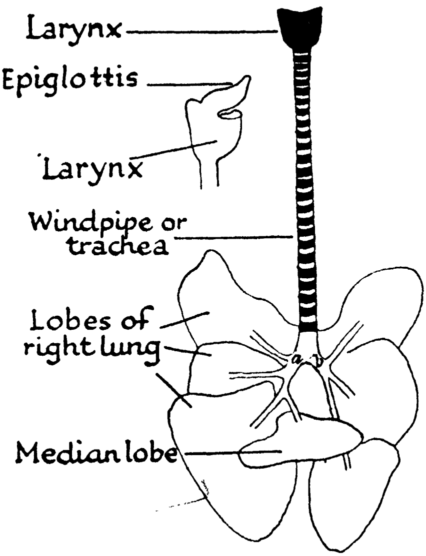


FIG. 19.—RESPIRATORY SYSTEM OF CAT. Lungs. × $\frac{3}{5}$. *a*, *b*, Bronchi. Larynx. × 1

The windpipe divides into two short branches or bronchi, one passing to each lung; these branches fork immediately into two. In the right lung each half divides again; one branch enters each of the three lobes, and the fourth enters the median lobe. There are now only the three lobes of the left lung to be supplied, so the anterior half divides to supply the two anterior lobes while the posterior half enters the third lobe (Fig. 21). In each lobe the branches divide repeatedly, the divisions getting smaller and smaller until at last they form capillaries, each ending in a tiny balloon or air sac.

The pulmonary artery divides in the same way as the trachea to send a branch to each lobe of the lung, and the branches of the arteries form capillaries around the air sacs. These capillaries unite to form veins which join others, and finally a main vein conveys the blood from each lobe. In the right lung the veins in the two anterior lobes join, and the veins in the posterior and mid-central lobes: in the left lung only the veins from the two anterior lobes unite, and so two veins from each lung take the blood to the left auricle.

These networks of air tubes and blood vessels are held together by cells forming connective tissue. Any collection of cells of the same kind, and doing the same kind of work, is called a tissue.

How does the air get into the lungs, and how is the blood purified? Put your hands on the sides of your chest and take a deep breath. You should be able to feel your ribs rise and the size of your thorax increase considerably. Now breathe out slowly and notice the lowering of your ribs and the decrease in size of the thorax. In the same way, in breathing in, or inspiration, the cat's ribs are pulled up by the muscles between them to increase the cavity of the thorax and air rushes through the nostrils into the trachea, filling the air tubes and sacs so that the lungs swell out to fill the space, somewhat like a sponge swells when it absorbs water. Other muscles now pull the ribs back, so that the wall of the thorax presses on the lungs and squeezes out the air. The cavity of the thorax is also further increased and decreased by the fall and rise of the muscular partition, the diaphragm, at the base of the thorax. When the ribs rise the highly arched diaphragm is flattened, and so the cavity becomes longer as well as wider. When the ribs fall the diaphragm arches again and presses on the base of the lungs.

When air enters the thin-walled air sacs oxygen rapidly passes into the capillaries, releasing the waste carbon products, which pass into each air sac as carbon dioxide, while the bright red corpuscles flow on into the veins. In breathing out, or expiration, only some of the air is expelled from the lungs. It is the remaining or residual air which makes the lungs buoyant, so that they easily float on water and are so light that butchers speak of them as "lights".

When breathing takes place in the usual way, the air passes quietly in and out, but when the cat makes sounds, the air is directed between muscular cords and folds stretched across the larynx. The two vocal cords vibrate like the strings of an instrument, and by changing the lengths of the cords the cat can vary its mewing and can produce the serenades sometimes described as caterwauling. The muscular folds vibrate more slowly, and probably produce the purring sounds.

THE BRAIN AND NERVES.

A large business firm has a central office with a staff to receive and answer inquiries, to file and store information, and to make plans for the development and control of the various branches of the business. To facilitate the work, this central office can communicate directly by telephone with offices and branches in other localities.

The brain of the cat, or of any other animal, corresponds to the central office: the nerves, like the telephone wires, act as lines of communication, and connect the brain with all parts of the body. Without the brain there can be no hearing, no sight, no pain, nor feeling of any kind, and thinking is impossible.

The cat's brain is pale grey, and divided by a deep groove into right and left halves covered with a skin in which there are numerous blood capillaries. This skin really consists of three membranes, and is quite tough in the adult cat, but very thin and delicate in the young kitten. The two large lobes of the anterior part of the brain partly cover two smaller posterior ones. The large lobes have many folds or convolutions in them, and form the cerebrum: the smaller lobes form the cerebellum, which helps to control the balance of the animal. The cat's cerebellum is very well developed, and this may account for the ease with which the cat walks along a narrow ledge or jumps from branch to branch of a tree.

Between the lobes is a part known as the spinal bulb, and from the posterior end of this passes out the spinal cord, the largest collection of communication cords to be found in the body. This important cable runs through the canals in the vertebræ, and branches pass between the junctions of these bones to and from the limbs, lungs, heart, digestive system, and all parts of the body. Two short branches pass directly from the cerebrum to the eyes, two others to the nose, and others to the ears and tongue.

In the middle of the ventral surface of the brain is a small rounded body, the pituitary gland. This is believed to be of

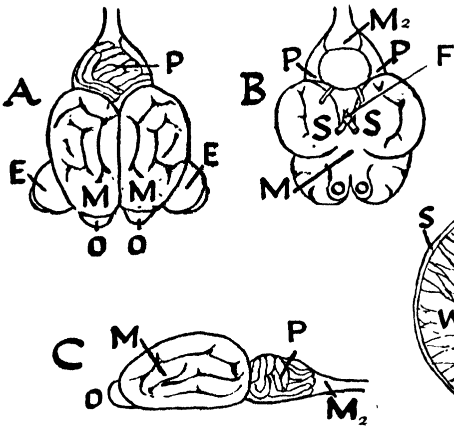
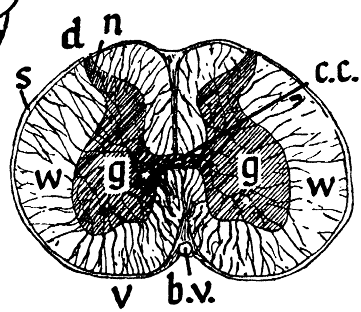


FIG. 20.—BRAIN OF KITTEN. × ½.

A. Dorsal view of Brain.
B. Ventral view. C. Lateral view.
O. Olfactory nerves (i.e. nerves of smell).
M. Cerebrum. E. Eyes.
P. Cerebellum. F. Pituitary gland.
M_2. Medulla oblongata or spinal bulb.
S. Roots of optic nerves.



TRANSVERSE SECTION OF SPINAL CORD (diagrammatic)—

d. Dorsal side; *v*, Ventral side; *s*, Skin *g*, Grey matter; *w*, White matter; *n*, Nerves leading from grey matter; *b.v.*, Blood vessel; *c.c.*, Central canal.
× 2.

great importance in the human being, and probably plays some part in the development of the cat.

The brain and spinal bulb consist mostly of grey nerve cells, having fine extensions linking them up in all directions with other nerve cells. Some of these give out long, slender fibres which are connected with others to form long communicating threads. Several fibres bound together in a bunch form a nerve, which may be seen as a white thread. The inner part of the brain and outer part of the spinal cord consist of nerve fibres, while the centre of the cord, like the greater part of

6

the brain, consists of the grey nerve cells. On some of the larger nerves branching from the spinal cord are small swellings called ganglia, and in these there are nerve cells. Each ganglion acts somewhat like a local office in regulating and controlling processes which do not need to be referred to the brain.

When you touch an object the pressure passes through your skin to the nerve endings lying beneath. This corresponds to speaking into the telephone receiver. The message passes instantaneously along the wire, the nerve, to the head office, the cerebrum, which decides whether the feeling is pleasant or unpleasant. If it be pleasant a message will be sent to the nerves controlling the muscles, which will enable you to continue to touch the object. If the feeling be unpleasant a message will be sent to the muscles which will withdraw you from the object. Similarly, your cerebrum will decide whether a picture is pleasing or not. If not, a message may be sent to the muscles of your eyelids or of your neck or legs, so that your eyes may be closed, or your head turned away, or you may walk away. So in all vertebrate animals the cerebrum receives impressions or sensations, and deals with them in various ways. It also stores them in some mysterious way, and this collection of information may be drawn upon, and constitutes what we call memory. The cat remembers people and places, and any tricks you may have trained it to perform. The cerebrum, too, is a means of thinking and of willing to do things. That the cat is able to think and to carry out some course of action is shown by the following example, and if you have kept a cat you will be able to give many other examples. A cat which used to be fed in the kitchen of a farm disappeared for a few days. One morning she reappeared and, by mewing and running to and from the kitchen door, showed plainly that she wanted someone to go out with her. She led a girl to a high bench in an orchard, and there in a barrel was a kitten. The mother showed that she wanted the kitten lifted out, but when the girl started carrying it toward the house the cat became very angry and attacked her. She put the kitten on the ground, and its mother immediately picked it up in her mouth and carried it to the kitchen. In the evening she carried it back into the barrel again. She repeated these performances every day until the kitten was too heavy for her to carry.

The spinal bulb controls breathing, circulation, digestion, and all the internal processes of the body. Existence would be impossible if these processes were controlled by the cerebrum, so that the animal had to think about their control.

Special structures such as the brain, lungs, stomach, and heart, which have been built of different kinds of highly specialised cells, and do special work, are called organs. Wherever necessary the organs are held in place by thin skin, or mesentery. A collection of organs, working together for the same purpose, forms a system. For example, all the organs helping to dissolve the food form the digestive system.

The Skeleton.

The brain of the animal is so important and so delicate that it needs the special protection afforded by the skull. This is thin in the young kitten, but soon becomes thicker and very hard. If you try to imagine a cat with a head containing no skull you will realise at once that the skull serves other purposes. To it are attached the muscles of the face and scalp. In bony sockets the eyes and their muscles fit, there are sockets for the teeth, and there is at the base of the skull an opening through which the spinal cord passes. The only movable part is the lower jaw. This is attached to the upper jaw, and works up and down, and slightly from side to side. The bones of the skull are very firmly dovetailed together, and are described as *flat* bones to distinguish them from *round* bones, such as those of the limbs.

Just as the muscles of the head need a firm surface for their attachment, the muscles of the limbs and trunk also need a firm attachment to enable the cat to move as it does, and some of the organs need special protection. The main supporting axis is the backbone, which runs dorsally from the base of the skull to the tip of the tail. It consists of a large number of vertebræ, thirty in the body, and a variable number in the tail.

At the base of the skull are two rounded parts which fit into the two shallow sockets of the first or atlas vertebra, so named after Atlas, who carried the world on his shoulders. This joint allows the head to nod and to rock from side to side. The atlas vertebra is a bony ring which hangs on an axis projecting from the second, or axis, vertebra. The atlas, turning on this axis, enables the cat to turn its head. (Plate I.)

The ventral part of a vertebra is called the body. The dorsal part is a bony arch bearing a central spine, and one or more spines on either side, and forming a canal through which the spinal cord runs. Following the seven vertebræ of the neck are thirteen each with a rib attached on either side. The ribs are slender flat bones arched round the thorax, protecting the lungs and supporting the muscles used in respiration. Ventrally, the first nine pairs are attached to the breast bone or sternum, a flat bone running from the base of the neck over half the length of the thorax. Dorsally the ribs are attached to the vertebræ by the end or head of a rib and a small rounded projection, fitting into special parts of the vertebræ and making possible the turning movement necessary to raise the ribs in breathing. The first ribs are very short, but the size of the pairs increases until the ninth. The cavity of the thorax continues to increase posteriorly because the next three pairs of ribs are not brought right round to the mid-ventral surface, but curve up to join the preceding pairs. The ribs of the thirteenth pair are joined only to the vertebræ, and are free at the other end. These are called "floating" ribs.

All except the last three of the body vertebræ are connected by pads of gristle or cartilage, which act as buffers preventing jarring when the cat jumps, and through which the blood vessels and nerves can pass. This cartilage is flexible and allows the cat to arch its back considerably—as it usually does when it meets a dog—and to twist its body as it does when washing itself, and in making other movements.

The last three body vertebræ are fused to make a strong wedge or keystone for the bones supporting the hind legs. These bones are firmly joined together to form a ring called the pelvic or hip girdle (L. *pelvis*, a basin). At the anterior end of the body is the pectoral (L. *pectus*, the breast) or shoulder girdle, which supports the fore legs, but this is not nearly so well developed in the cat as in many other animals. It is formed by the shoulder-blades and collar-bones.

To get an idea of a well-developed girdle, feel your own collar-bone and its connection with the breast-bone and shoulder-blade. The cat's collar-bone is very fine and pointed, and meets neither the breast-bone nor the shoulder-blade. If you tried to jump and spring on all-fours like the cat does, your collar-bone would soon be snapped by the strain due to the pressure on the shoulders. In the cat, the frog, and other jumping animals the possibility of this accident is removed by the incomplete pectoral girdle.

At the joints, all the bones are connected by strong cords or bands of tough white tissue. These are ligaments, and in some joints, the hip joint for example, both forms of ligament keep the bones securely in place, but allow a certain amount of movement.

The fore legs correspond to our arms, and have similar bones. In the upper leg is a single bone, the humerus, which has a rounded upper end or head fitting into a shallow socket in the shoulder-blade. There are two bones in the lower fore leg, and these both have a hollow socket into which the lower end of the humerus fits. One of these bones, the ulna, has a projection which passes beyond the joint and helps to prevent backward bending of the limb. This projection is similar to the one at your elbow, preventing you from bending your forearm back. The other bone, the radius, is attached to the lower end of the ulna in such a way that its head can rotate slightly and turn the paw in much the same way as you turn your hand palm downward or upward. By holding your forearm between your finger and thumb you may feel the radius crossing the ulna when you turn your hand.

At the lower end of these bones are several small ones forming the "wrist". One of these projects somewhat, and its position may easily be seen and felt a short distance above the paw. Each of the four long toes has three bones: the shortest toe has only two. The claw with its bony case is at the end of each toe.

The hind legs are similar in structure to the fore legs, but the bones are longer. The upper bone is the femur, and has a much more rounded head than the humerus. It fits into a deep cup-shaped socket in the pelvic girdle, forming a cup and ball or ball and socket joint. In jumping, the whole body is pushed by the hind legs, and, if this socket were not deep, the femur would slip out and be dislocated. In the lower leg is a long thick bone, the tibia, corresponding to the radius, and a very slender one, the fibula or brooch bone, corresponding to the ulna. There is no projection at the joint, which is formed by the rounded head of the femur resting in the hollow socket of the tibia. The fibula is attached at both ends to the tibia. The ankle joint, like the "wrist", consists of a number of bones, and the heel projects considerably. There are only four toes, all having three joints.

Bones are all built up by cells which have caused mineral matter to be deposited. Through numerous tiny canals in the bones the blood vessels pass to feed the cells, supply more mineral matter, and carry off waste. These blood vessels can best be seen in the centre or marrow of the bone, and it is here that new supplies of red corpuscles are made.

Attached to the bones are muscles. These are made up of long, narrow cells, and a collection of these cells enclosed in a fine skin forms a muscle fibre. All lean meat is muscle, and when meat has been stewed for a long time you can easily separate the fibres. The muscles have at each end a tough white, flexible tendon which is attached to the bone. You can find tendons when you have the limbs of a chicken or rabbit for dinner, or when you look at some of the large "joints" in a butcher's shop. You should also be able to see the ligaments.

The wall of the heart is a highly specialised muscle, and its cells are quite different from those of the other muscles.

Reproduction.

Like the *Hydra*, the cat develops from a fertilised egg-cell, but whereas the *Hydra* produces both male and female gametes, the cat is able to produce only one kind, so that the terms male and female may now be applied to the whole animal. In the female cat the egg-cells develop; in the male, the spermatozoa.

The egg-cells, or ova, grow in two ovaries, one lying by the side of each kidney of the female. The ova pass by amœboid movements through a duct opening into a small bag, the uterus. This has very muscular walls, which may be considerably stretched. When the ova are fertilised they are held by the lining of the uterus, and divide and grow into tiny animals, which are born at the end of eight weeks; that is, they pass through a tube, the vagina, leading from the uterus to the exterior. If the ova remain unfertilised they will pass out or will die unnoticed because they are so minute.

The male cat has two testes, situated in a position comparable to that of the ovaries. In the testes the spermatozoa are developed, and pass down a duct opening into a sac, where they are stored until they are transferred to the female cat. Each spermatozoon is similar to that of the *Hydra*, and by means of its flagellum can move through the vagina to the uterus, where it dies if it does not fertilise an ovum.

The greatest possible protection of the young animals is afforded by the development inside the mother. Nothing, except injury to the mother, can injure the developing ova.

When first born the kitten is blind and helpless. Its eyelids begin to unclose when it is about a week old, but it cannot see until the tenth day. A few teeth may appear during the first five days, but until the kitten is able to feed itself the mother feeds it with milk from her glands. In the Mammalia the mother usually takes care of the young until they can look after themselves, but a mother should never be frightened or disturbed when the young ones are born, for then she may leave them altogether, or she may kill them by kicking or trampling on them, or she may even eat them. She should be given a comfortable box, placed in a dim corner, and well lined with something soft, such as an old rug or garment; some cats prefer paper. The rabbit and all wild animals make their own nests, and often line them with the loose fur torn from their bodies. The domestic cat will often refuse any "nest" you provide for her, and make one inside a hat-box or under an eiderdown should an opportunity occur.[1]

When studying animals it is best to try to record your observations in a definite order, and to make a thorough examination of one part before proceeding to describe another. The arrangement suggested here may help you with your practical work.

Habitat.

Where does the animal live naturally?

General Appearance.

What is the size, colour, shape, and covering of the animal? Is its body divided into parts? If so, count and describe them. Are there any appendages (these are any outgrowths such as fins, wings, legs)? If any be present, find whether there are any differences between them, and what such differences are. How many joints has each appendage?

Senses.

1. *Has the animal any sense of feeling?* To discover this, you can devise several simple experiments without hurting the animal. Always remember to avoid causing any pain.

2. *Can the animal see?* If so, has it a keen sense of sight, or a poor one, or one that is moderately good? Can the animal detect quick movement? If no eyes be present, is the animal at all sensitive to light? To find out this, use a pocket lens to focus rays from the sun or any

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[1] In this chapter the measurements and diagrams of the internal organs were made from a kitten just under six inches long and only five days old.

source of light, on different parts of the body. Do not keep the light shining on any one part for more than a few seconds, because the heat rays are also concentrated by the lens, and you will be unable to tell whether your result is due to the light or the heat. Moreover, the heat may injure the animal.

3. *Has the animal any sense of smell?* If you know of any odorous food that the animal may like, hide it within reach of the animal. Try to find the greatest distance at which it can smell such food.

Try the effect of any perfume, such as oil of lavender.

4. *Can the animal hear?* It is difficult to devise any satisfactory experiment to test an animal's power to hear. A snail or worm, for instance, might hear a voice or a bell, and pay no attention to either, because neither has any meaning for the animal. We ourselves pay no attention to hundreds of sounds every day because we are not interested in them. Consequently, in trying to test hearing, try to make some sound which might occur in the natural life of the animal. In the soil, if the worm can hear, it might notice the scratching sounds made by other soil-dwellers.

Habits.

How and when does the animal feed? Can it sleep? If so, how many eyelids has it, and how do they work? If not, does the animal rest, and when and where does it do so?

How and where does the animal pass the winter?

Does it make any special preparations for this time of year?

Movement.

Does the animal glide, walk, jump, swim, fly? If it have any special appendages to enable it to move, notice the manner and the order of movement of these.

Does its method of movement help to fit it for its mode of life?

Food.

What kind of food does it eat? How does it get food? Describe its manner of feeding. Notice the position of the mouth, and if teeth be present find out how many kinds there are, and how they are arranged.

Breathing.

Every animal takes in air. Find, if you can, how it does so. Is the breathing regular?

Enemies.

Has the animal any enemies? What are they? *How does it protect itself from them?*

Reproduction.

If the animal lay eggs, try to find out the time of year and where they are laid.

Does the parent look after the eggs at all? When you have discovered the natural conditions under which the eggs develop, collect some eggs and keep them under similar conditions. Find out the time of hatching.

Does the animal which emerges from the egg resemble the animal you studied? If not, find out what differences there are, and what changes take place before the animal is completely developed.

General Notes.

Has the animal any skeleton? When it has bones within it, it has an internal skeleton; when, like the crab or the beetle, it has a hard outer coat, the skeleton is external.

Are there any signs of a blood system? Can you detect a heart-beat?

How long does the animal live?

Make a list of all the special characteristics which fit it for its mode of life.

If possible, visit the Zoological Gardens and the Natural History Museum and try to find there any relatives of the animal you have studied. Do its relatives seem to be more, less, or equally successful in life? How do they compare with regard to numbers, size, structure? Try to account for any differences. Always draw the animal entire, and its parts separately. Make your drawings clear, large, and accurate, and name all the parts.

PRACTICAL WORK

In the way described in this chapter study the following animals:—

1. Cat
2. Dog
3. Horse
4. Cow
5. Sheep
6. Rabbit
7. Mouse
8. Collect footprints of a cat, dog, sheep, mouse, and rabbit.
9. Compare your drawings of the feet of the cat, horse, and sheep. What differences are there?
10. Draw the tail of the cat, horse, cow, and rabbit. What is the use of the tail to each of these animals?

11. Add a few grains of starch to some saliva in a test tube and keep it at a temperature of 98° F. Allow it to stand for ten minutes and then at intervals of five minutes take out a drop at the end of a glass rod and add it to a drop of iodine on a white dish or tile. Compare your results with that obtained by adding a drop of iodine to some fresh grains of starch.

12. Put a bone in a cake tin (or on a sand bath if you can work in a laboratory) and heat it in a very hot oven, or on a hot grate, until no fumes rise from it. Gently touch the bone after it has cooled.

13. Get a bone similar to the one used in the last experiment, and stand it in hydrochloric acid (spirits of salt) for some days. Pour off the acid, wash the bone well without handling it until the acid is washed away, then handle the bone.

From these two experiments say what you have discovered about the structure of bone.

14. Fix a hose, or any long piece of rubber tubing, on a tap. Turn the water on fully, then turn it off. Repeat this several times as quickly as possible and watch the tubing. From your observations try to explain the beating of the pulse.

Get some pig's "lights" from a butcher. They cost only a few pence, and the butcher will leave the windpipe attached if you ask him to do so when ordering the "lights". Use them for experiments 15–17.

15. Insert the end of a bicycle pump into the trachea and pump air into the lungs. Describe what you see.

16. Examine the surface of the lungs; notice the lobes, the structure of the windpipe and the roots of the blood vessels. Make a sketch of the whole.

17. With a sharp penknife cut the trachea and follow its branches to the lungs. Cut along the branches until they become too fine to follow farther.

Get a pig's heart from the butcher. (The pig's heart and lungs are cheaper than the sheep's or bull's.) Use it for experiments 18–20.

18. Look round the roots of the blood vessels and try to find traces of the pericardium.

Draw the heart and indicate the auricles and ventricles and the blood vessels.

How can you tell, without cutting the heart, where the auricles end and ventricles begin?

19. Cut open one side of the heart, being careful not to cut any blood vessels. Feel the wall of the auricle and of the ventricle, and compare

the two. Take a thin pen-holder and pass it through the artery opening into the ventricle. Cut open this artery, and look for the semi-lunar valves. Hold it under water to fill the valves. Draw them.

20. Repeat experiment 19, using the other side of the heart. Compare the sizes of the two ventricles and the thickness of their walls.

Cut open the veins leading into both auricles and look for semi-lunar valves.

Examine the valves which prevent blood from flowing from the ventricles to the auricles.

EXERCISES AND QUESTIONS

How are the following animals specially fitted for their habitat:—

1. Tiger? 2. Camel? 3. Giraffe? 4. Rabbit?

5. Many mammals which have long legs have long necks. Why should this be so?

6. Give an example of two mammals which have long legs and a short neck. How do these mammals get their food?

7. Make a list of animals which walk on their toes.

8. Make a list of animals which walk on the entire sole of the foot.

9. Explain why the terms *anterior* and *posterior* cannot be applied to *Amœba*.

10. Why are the terms *dorsal* and *ventral* of no use in a description of *Hydra*?

11. What are the differences between the hind and fore limbs of the cat? Name some other animals with similar differences.

12. Make a list of the differences between the cat and dog.

13. Make a list of the ways in which the cat resembles a dog.

14. Which kinds of teeth would you expect a rabbit and a cow to have? Give your reasons.

15. What is a gland? Name four kinds of glands found in the cat, and say what work is done by three of them.

16. What is an enzyme? What does the name mean, and why was it given?

17. State the uses of enzymes to the cat.

18. Account for the great length of the small intestine of a mammal.

19. Write as complete an account as you can of the production of soap by the cat. What becomes of the soap?

20. Describe the way in which air is drawn into, and expelled from, the body.

21. State the work of the heart, and give an account of the way in which this work is carried on.

22. What are arteries, veins, and capillaries?

23. Give examples of a vein carrying pure blood, an artery carrying impure blood; capillaries in which the blood becomes more pure as it passes through, and capillaries in which it becomes more impure.

24. Name the organs removing waste products from the body. In what forms are these products removed?

25. Give an account of the blood corpuscles and their work.

26. What are the uses of an internal skeleton?

27. What enables the cat to move its head up and down?

28. How is it that the cat is able to turn its head round?

29. Why should the backbone consist of several small bones instead of a solid rod?

30. Name some animals in which you would expect the collar-bone to be very well developed, and give your reasons.

31. Name some animals in which you would expect the collar-bone to be very poorly developed. Give your reasons.

32. Account for the projection on the cat's hind leg.

33. Which parts of the nervous system control thought, breathing, hearing, kicking, memory, balance, sight, taste, digestion, speech?

34. Give some instances to show that a cat has memory.

35. Give some examples which show that a cat thinks.

36. What do you understand by an *organ* of the body? Name six organs in the cat.

37. Distinguish between tendons and ligaments.

38. What is a tissue? Name three different kinds of body tissues.

39. Why is it that the cat is spoken of either as "he" or "she", and the *Hydra* as "it"?

40. Show that, in the cat, specialisation of cells is much more advanced than in the *Hydra*.

CHAPTER V

HOW TO STUDY A PLANT

The Sweet Pea

How does the sweet pea plant, from three to six feet high, grow from a small round seed about one-fifth of an inch in diameter? Get a few sweet pea seeds from a seedsman and examine them. They are hard, greyish-brown spheres with a light elliptical scar having a ridge through its centre, and a tiny brown protuberance at one end of it. The scar was made

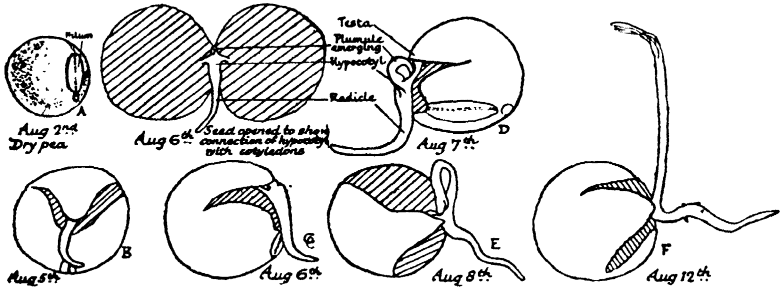


FIG. 21.—STAGES IN GERMINATION OF SWEET PEA GROWN ON MOIST COTTON WOOL. × 2.

by the detachment of the seed from its minute stalk in the pod.

Soak some of the seeds in water for a day and then spread them on moist cotton wool in a dish. The cotton wool is best prepared by soaking it in water, afterwards squeezing it dry, as you would a sponge, and then pulling it apart to loosen it. Keep it moist by pouring a little water, when necessary, into the dish. See that the water-level remains below the seeds. Look at them every day and draw them whenever there is a marked change in their appearance.

Compare the size of the soaked seeds with that of the dry ones and you will find that soaking has caused a considerable increase in the volume of the seed. Water has been absorbed, and if you squeeze a seed you may see a drop of water come out from a minute opening between the end of the scar and the protuberance. Carefully remove the seed coat or testa (L. *testa*, a shell), and notice that on its inner surface at one end of the scar is a little pocket into which the tip of a narrow triangular structure, the radicle, fits.[1] Notice how easily the peeled seed separates into two parts joined by tiny outgrowths near the base of the radicle. Between the parts is the curved plumule (Fig. 26).

When growth begins the testa splits irregularly, but always in such a way that the radicle can grow out quite easily. In fact, it is the growth of this that has helped to cause the splitting. A day or two later the plumule appears, still bent like a hook, and when its tip has emerged you will be able to see on it tiny leaves folded together. The plumule forms the shoot and the radicle the root of the seedling. While these parts are enclosed within the seed coat the young plant is called an embryo; the young root is the radicle, and the shoot the plumule. Between the plumule and radicle are two very short stalks connecting them with the two fleshy parts of the embryo. These stalks are easily seen when the plumule begins to grow out.

As the young plant grows, the root sends out branches, and the leaves unfold. The roots of seedlings of some plants send out many tiny hairs to absorb moisture, but no root hairs were visible on the seedlings grown on cotton wool, and shown in the diagrams here. Although many branches may be formed, the main root remains distinct and forms a tap root system. In the grasses, and many other plants, the main

[1] Particulars of the way to sow your seeds and the kind of records to keep will be found in Chapter XI.

root, while still quite young, ceases to grow, and other roots grow from the base of the stem. Such roots form a fibrous root system, and the roots are described as "false" or *adventitious* because they do not grow from the main root or its branches.

Meanwhile the two fleshy parts of the seed shrivel and become smaller and smaller until nothing can be seen of them. Thus the larger part of the embryo has dwindled away, and the smaller part has become a plant several inches long!

If you were going to the North Pole, or exploring in a region where you would probably be unable to get food supplies, you would take with you a good stock of provisions. In selecting your stock, you would, if you were wise, choose foods that would keep indefinitely, and that would occupy as small a space as possible.

The food problem of the young plant is very similar. Handicapped by its small size and its inability to provide food for itself to start its growth, it is sent on a voyage of exploration. It may arrive at a place where food is plentiful, and where, as soon as the radicle has entered the soil and the plumule expanded, it can secure as much food as it needs. On the other hand, it may settle where it has to compete with other well-established plants in order to get food, so it starts its journey with good food supplies, highly concentrated, so that they can be packed in a small space. In the sweet pea, these supplies are packed in the fleshy structures, which are really two leaves, the cotyledons (Gk. *kotyledon*, a cup), often spoken of as the "seed-leaves" because they are the best developed leaves in the seed. When the seed settles down and absorbs moisture, the young plant begins to draw on its food supplies. Highly concentrated foods, however, are usually difficult to dissolve, and plant seeds have especial need of insoluble food stores, otherwise the supplies would soon be washed out by the rain or soak out in moist soil. The embryo needs dissolved food, and this is provided by the action of an enzyme [1] in the cotyledons.

[1] See page 56.

This enzyme changes the food, as it is required, into substances which dissolve in the absorbed water and are carried through the short stalks to the growing radicle and plumule.

Certain seeds, like those of the castor oil and ash, have very thin cotyledons lying on a separate food store on either side of the embryo. Such a separate food supply is described as endosperm. The sweet pea has no endosperm.

The cotyledons of the sweet pea always remain below the soil. Those of the sunflower, beech, and sycamore are raised above it by an axis called the hypocotyl: it is neither stem nor root, as its internal structure resembles that of both stem and root. The hypocotyl of the sweet pea, and of other plants with cotyledons remaining below the soil, is very short and is at the junction of the cotyledons with the axis. The true stem begins above the hypocotyl, and below it, the true root.

The green flattened stem, too weak to support itself, trails on the ground if no support be given to it. On the upper part it has flat, almost leafy margins, and its rough surface has narrow longitudinal grooves and ridges, that is, it is ribbed.

The leaves grow singly from the stem and are arranged in spirals so that no leaf hides any other: all can get their share of air and sunlight. Both stem and leaves are green. On either side of the base of each leaf is a small leafy outgrowth or stipule (L. *stipula*, a little stalk) divided into two narrow pointed parts, one longer than the other. The leaf stalk or petiole is flattened and grooved—like an iron gutter in shape—and has on each edge a thin flat leafy margin. A pair of leaflets grows from the petiole. Each leaflet is long and almost elliptical and its margin is entire, that is, it is not divided in any way. A main vein, the mid-rib, runs through the centre of the leaflet and at its base several branch veins arise and run almost parallel to the mid-rib. Between these branches are various cross connections, so that a whole network of veins can be seen when the leaf is held up to the light. The word "vein" has a different meaning when applied to a plant from the meaning given in connection with animals. In the plant, a "vein" is a collection of cells specially fitted for carrying food and for supporting the plant, in much the same way as a skeleton supports the soft parts of an animal. Between the leaflets of the lower leaves of the seedling is a short tubular outgrowth, which may be only about a tenth of an inch long. On the upper leaves, this outgrowth becomes much longer, forming a tendril which will curve as the direction of the light changes, or when it touches a solid, coiling round it to attach the plant, which has not enough "skeleton"

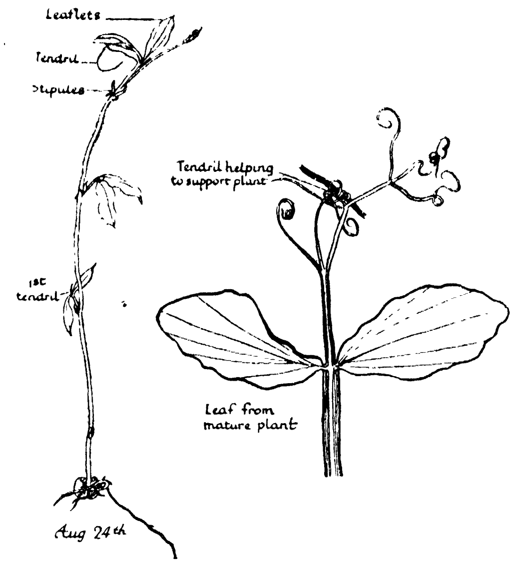


FIG. 22.—FURTHER DEVELOPMENT OF PEA SHOWN IN FIG. 21. × ½.

to enable it to keep erect. It is often possible to watch a tendril move: under suitable conditions it will make half a revolution in twenty minutes. As the plant continues to grow, it produces leaves which have one, three, five, or even as many as nine, tendrils. Notice that there is always an odd terminal one, while the others are arranged in pairs. If you compare the leaf of the sweet pea with that of a rose or elder you will see that the arrangement is very similar. In each case there is a main leaf stalk or petiole, and the leaflets are arranged in pairs, but in the sweet pea all the leaflets, except the first pair, very early in their development have been modified, or changed, to form tendrils. A whole leaf which has several leaflets is described as compound, to distinguish it from a simple leaf, such as that of the oak or ivy.

The two first leaflets have a distinct upper and lower surface, and so are described as dorsiventral. The tendrils may be about three or four inches long and wind round sticks, or the stems of other plants, to raise the sweet pea.

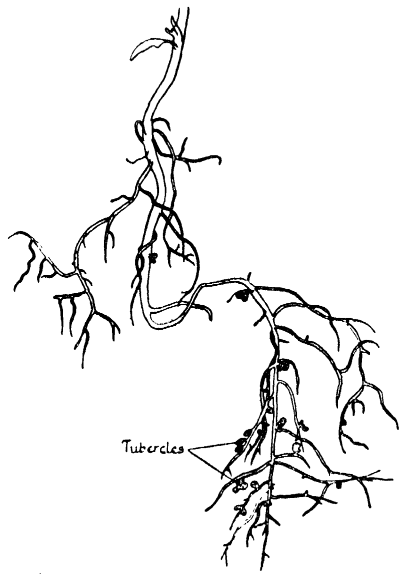


FIG. 23.—ROOT OF SWEET PEA (TAP-ROOT SYSTEM). × ⅓.

Dig up a healthy sweet pea without injuring the root. You will find that this is several inches long and has very many branches, the youngest ones being near the tip of the root and the oldest near the hypocotyl. Small rounded irregular swellings or tubercles (L. *tuberculum*, a little swelling) are present on many of the branches and on the main root. The tubercles are formed by bacteria which live inside the root and help to build the foods containing nitrogen that the plant needs. You will find no tubercles on the roots of grass, daisy, rose, nor of most plants, but you may find them on roots of clover and of many other plants belonging to the sweet pea family, the *Leguminosæ*.

In summer and early autumn the flowers appear first as small green buds growing in the angle or axil, between the leaf and stem. The flower stalk, the peduncle, grows quickly and bears from two to five flowers. The outer part of each flower is formed by five small green leaves, slightly unequal

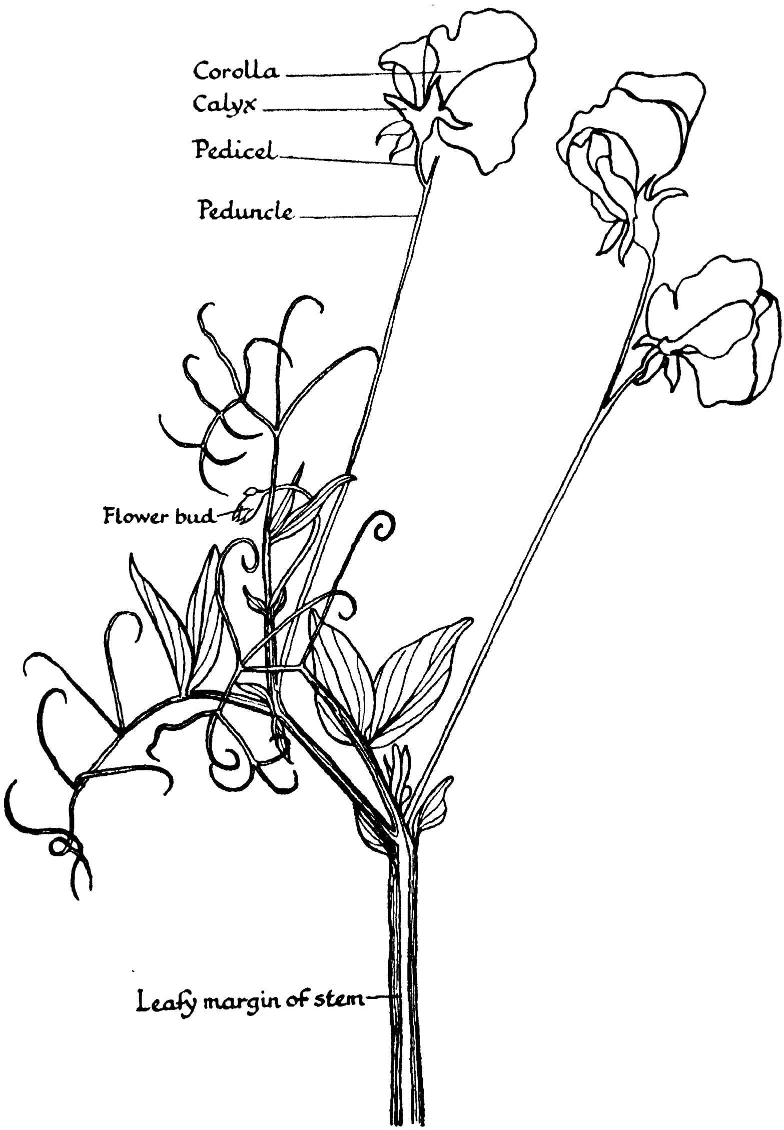


FIG. 24.—BRANCH OF SWEET PEA. × ⅜.

in size and joined at their bases to form a cup. These special leaves are the sepals, and together they form the calyx (Gk. *kalyx*, cover). As its name implies, it covers the other parts of the flower and protects them from cold, wet, and from the attacks of hungry insects. It also helps to support them.

Directly within the calyx are the coloured parts, the petals, which together form the corolla (L. *corolla*, a little crown). There are five petals, much more unequal in size than the sepals. The largest and outermost is called the standard; it has a very broad upper part, the lamina, and a very short narrow base or claw. Within it, on either side of the flower, are two smaller petals, the wings, broad at the top, and each

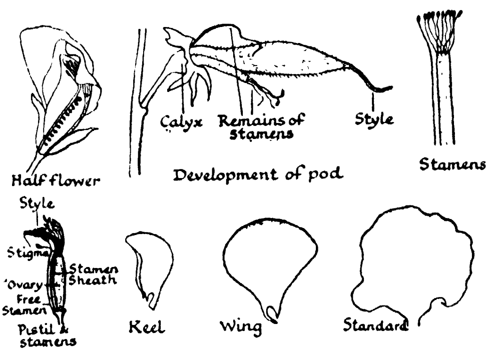


FIG. 25.—PARTS OF FLOWER OF SWEET PEA.
Stamens. $\times \frac{3}{5}$. Other diagrams. $\times \frac{3}{10}$.

having two narrow projections at the base forming the sides of an arch. Opposite the standard and within the wings are two petals joined to form a boat-shaped part, the keel, which has an outgrowth or peg on each side fitting into the arch at the base of each wing. The use of such an arrangement will be seen after the inner parts of the flower have been observed.

Hidden by the keel are ten small yellow heads, on tiny stalks. Nine of the stalks are joined, the tenth, nearest the standard, is free. The head is an anther (Gk. *antheros*, flowery), the stalk the filament (L. *filum*, a thread), and the two together form a stamen. The stamens are curved so that the anthers lie just within the tip of the keel and near the opening. When the anthers are ripe, yellow powder, the pollen, is shed and collects in the tip of the keel. You must have seen similar yellow powder on the noses of people who have vigorously smelt lilies, for the anthers of lilies produce large quantities of pollen. Together the stamens form the andrœcium (Gk. *andros*, male).

Projecting between the anthers is a rather thicker green "stalk" with a blunt end having just below it a tuft of hairs. At the base of this "stalk" is a long green structure very densely covered with white hairs and flattened from side to side. The whole of this inner part of the flower is the pistil or gynæcium (Gk. *gyne*, female): the "stalk" is the style (Gk. *stylos*, a pillar) and its tip the stigma. The flattened part is the seed-box or ovary, and within it is a row of small irregularly shaped green bodies, the ovules, each attached by a minute stalk to a ridge at one side of the ovary.

The sweet pea is like the *Hydra* in producing two sorts of gametes: the male gamete is developed in the pollen grain and the female gamete in the ovule. The male gametes of the *Hydra* could swim through the water to find an egg-cell, but the flower grows in air, its gametes cannot move, and the flower itself cannot carry them about. Consequently some other method has to be found to transfer a male gamete to a female one, for unless the egg-cell be fertilised no seed can be produced. As in the *Hydra*, the gametes themselves are very minute, so the whole pollen grain is transferred instead of only the gamete. During its development the gamete is thus protected by the coat of the pollen grain within which a certain amount of food is enclosed. The pollen has, by some means or other, to be transferred to the stigma of another flower, and this transfer is called pollination. The sweet pea has a most ingenious arrangement for securing pollination. Nectar is produced from tiny glands round the base of the ovary, on the disc or receptacle from which all the parts of the flower grow. The colour and sweet scent of the flower attract many insects to it, but the nectar is concealed between the ovary and the base of the sheath formed by the nine long stamens. Most smaller insects fail to reach the nectar, but when a large, long-tongued insect, such as a bee, alights, it usually alights on the wings, pushing them aside, so disturbing the arches at their bases and dislodging the pegs of the keel, which flies back. The style springs out, brushing the pollen from the tip of the keel to the ventral surface of the insect while it is putting its tongue through the opening between the free stamen and the sheath to suck up the nectar. The stigma touches the insect first, so when it flies to another flower the stigma of this rubs some pollen off the body, and the insect gets a fresh supply of pollen. Only pollen of the sweet pea is of use to help to produce seeds of the same plant: pollen from any other plant is useless. The bee, however, has a very curious habit most useful to plants. When collecting nectar or pollen the insect goes from flower to flower of the same kind, and, once it has started collecting, will pass by other flowers which would yield nectar more quickly, and which we might think would be better. In this way the bee conveys from flower to flower the right kind of pollen.

The flower of the sweet pea is so constructed that when the insect flies away the keel returns, enclosing the stamens and pistil as before, and bees will pay many visits to the same flower. This is particularly useful to the flower, if for any reason pollination be not accomplished during the first visit. Some other members of the *Leguminosæ* are less fortunate. If you look at the broom in flower you will be able to see at once which flowers have been visited by a bee, and which have not. The visited ones look untidy and bespoiled: the keel is split and hangs down, disclosing the stamens and pistil, and no bee visits the flower a second time.

The pollen grains deposited on the stigma are still a very long way from the ovules. Each grain sends out a tiny tube which grows down through the style, enters the ovary, and at last penetrates an ovule, and grows into it until it reaches the egg-cell. The male gamete develops in the pollen grain and is carried down at the tip of the tube. This breaks down and allows the gamete, which is a nucleus with a small amount of cytoplasm, to escape and fuse with the ovum, a nucleus with a larger amount of cytoplasm. This fusion is the fertilisation of the egg-cell, which now divides repeatedly and grows into the tiny embryo. The cotyledons receive their food stores from the parent plant, and the seed is fully developed. After fertilisation the ovule has become a seed and the corolla and stamens wither away, for their work is accomplished. The wall of the ovary grows as the seeds enlarge and the whole familiar pea pod is the fruit of the plant. When quite ripe, the pod splits into two parts and the seeds drop out.

If you put the open halves of the fruit side by side, so that the ridges bearing the seeds are on the outsides, and look at the wall of the ovary you will see that it looks something like a leaf with a pointed tip. In fact, it is a highly specialised leaf or carpel, folded about the mid-rib, and the seeds are attached along the margins which grow together very early in development. The stamens, too, are very specialised leaves, though it is less easy to see this except in flowers like the water-lily, where the filaments of the stamens are sometimes as broad as some of the smaller petals.

The seed starts its life well provided with food from the parent plant. How does the parent manage to provide the food? This question has been partly answered in the description of the feeding of the *Chlamydomonas*. Carbon dioxide and the mineral salts needed by the *Chlamydomonas* are also needed by the sweet pea and by any other plant containing chlorophyll, but whereas the *Chlamydomonas* obtained food supplies from the water, the land plants have to get them from the air and from the soil, and are enabled to do this by their structure. The root grows into the soil, and, while anchoring the plant, absorbs the solution of mineral salts to be found there. The shoot grows into the air, and all the parts containing chlorophyll are able in sunlight to make use of the carbon dioxide and build it into body substance and food stores. In the sweet pea the leafy margins of the stem and of the petioles help to provide a greater area for the absorption and manufacture of food to make up for the loss in area due to the formation of tendrils in the place of leaflets.

If you use the sweet pea in the experiments described in Chapter XIII you should be able to discover how this leafy margin helps in feeding, what foods the plant needs, and how it obtains them.

All parts of the plant breathe continually, using the inspired oxygen to break down the food materials to produce energy, as described for the *Chlamydomonas*, and breathing out the waste carbon dioxide. You may show this by using the sweet pea in the experiments described in Chapter XIV.

The Bluebell (Wild Hyacinth)

The bluebell is usuallygrown from bulbs, because the seeds are very much slower in producing a plant large enough to flower. Look at bluebells in a wood in late spring or early summer. Notice the long leaves, like wide blades of grass, growing vertically upward, so that you are unable to distinguish between an upper and lower surface as you can in the sweet pea. Such a leaf is described as bifacial. Petioles and stipules are absent: the leaves seem to form a tuft growing directly from the surface of the soil, and through the centre of the tuft rises a sturdy axis bearing several flowers.

Move the soil away from the leaves and trace their bases down to a white bulb. Growing from the disc at the base of the bulb you should be able to see several roots, but notice that there is no main axis like the tap root of the sweet pea. The roots are described as fibrous, and since they grow from the base of the stem, they are adventitious.

If you cut a bulb through its centre you will see that it is very similar in structure to a cut onion. Notice at the base the short conical, solid axis, from the apex of which the inflorescence and the foliage leaves are growing, while below, and enclosing them, are layers of broad, fleshy white leaves which in turn may be surrounded by a thin brown scale.

Growing in the axils of the fleshy leaves you may find one or more very tiny buds, which in time may become new bulbs.

The inflorescence may be about two feet high, or may be only four or five inches, according to the situation of the plant in shade or in a light, open place. It bears a number of blue, or occasionally white flowers, the youngest being at the top and the others arranged spirally round the stem in order of age, so that the lowest is the oldest. This inflorescence is a raceme and is similar to that of the sweet pea, but the bluebell raceme has usually more flowers. Each flower stalk, or pedicel, grows from the main axis, or peduncle, of the inflorescence, between two much deeper blue narrow pointed leaves or bracts.

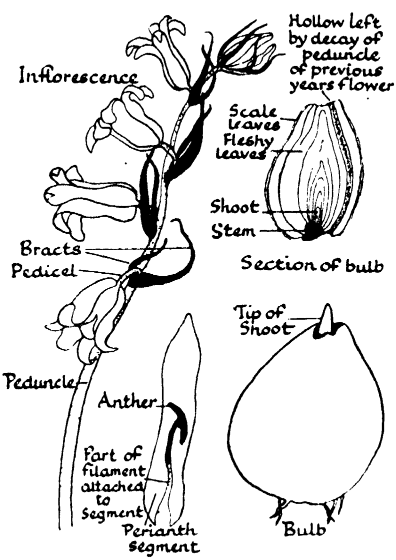


FIG. 26.—BLUEBELL. × ½.
Section of bulb. × ½. Bulb. × 1.
Perianth segment. × 1.

The flower has no separate calyx nor corolla. The blue part is called the perianth (Gk. *peri*, around; *anthos*, a flower), and each division of it a segment. The six narrow segments, three outer and three inner, are pointed at their tips. They may be removed separately, but in removing them you will find that you have also removed the stamens, one attached to the base of each segment. There are, then, six stamens, each with a filament a little more than half the length of a perianth segment, and a well developed anther, which bursts open along its inner surface to liberate the pollen. The anthers lie just within the entrance to the flower and surround the style which raises the stigma just above them. The stigma looks somewhat like a pin head. The style is rather thick and grows from a triangular ovary, each side of the triangle being indented in the middle. Cut the ovary across and notice that it is divided into three chambers, or loculi, each containing many ovules attached to the tissue of the inner angle or axil. You have found that the pistil of the sweet pea is formed from a single carpel. Imagine three such carpels with their edges joined together to form a cylinder. If the edges now be turned in so that the join extends part way along the sides of the carpel, and the three meet in the centre, the cylinder will be divided into three loculi. This joining or fusion of the carpels takes place very early in development. Ovules usually arise on the edges of the carpels, and since

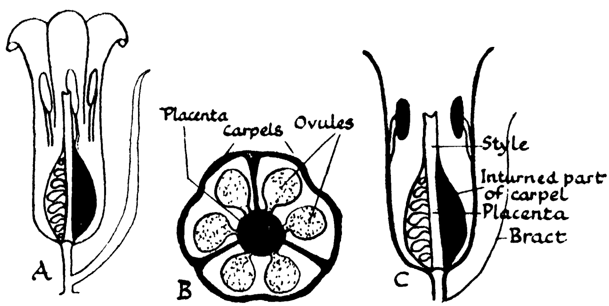


FIG. 27.—BLUEBELL.

A. Half flower. × 1½. B. Transverse section of ovary. × 4½.
C Longitudinal median section of flower. 1½.

in the bluebell these edges are in the middle of the ovary the ovules will be found there. The edges of the carpels become fleshy and form a cushion of tissue or placenta bearing the ovules, which are said to have axile placentation.

The fused tips of the carpels form the style and stigma.

The flowers are pollinated by insects, mainly bees, which take the nectar secreted by cells at the base of the ovary wall. After fertilisation the ovary grows into a fruit containing many tiny black seeds. The wall of the ripe fruit is light brown and papery. It splits into three parts, the three carpels, and the seeds are shaken out when the flower bends in the breeze.

Before the fruit is fully ripe the green leaves wither. They have been building up food and passing it down to their bases. It then entered the stem and was conveyed to the buds which have been growing larger, for in their outer leaves the food has been stored so that they have become fleshy, while in the centre are the delicate leaves which will form next year's shoot. As the fleshy leaves of the old bud have supplied the food for the growth of the green leaves and for flowering they have shrivelled, and very soon decay, so that the new bulbs—if more than one be formed—are separated. Their outer leaves are the white fleshy leaves, and these usually do not become scaly. After some time the thin membrane covering the outermost leaf may form a light brown, scaly covering. If the season is mild you may find the tip of the new shoot just emerging from the bulb in October, but since the bulbs are often a considerable depth in the soil the shoot will in most cases remain beneath the surface until the following spring.

Bluebell seeds are small, so that it is not easy to follow all the stages of their germination. The date-stone germinates in much the same way, and has the advantage of being seen easily. Examine a date-stone, and notice the groove along one side, and on the opposite side a small circular depression with a minute protuberance in the centre of it. At one end of the stone is a tough woody stalk which attached the seed to the ovary wall. Place a knife-blade in the groove of the seed, and tap it gently but firmly with a small hammer to drive the knife through the centre of the protuberance on the other side of the seed. Look at the cut surface. Along the groove you will see a narrow woody strand which was the continuation of that of the stalk. Most of the surface is white and very hard, like vegetable ivory. The small protuberance concealed a soft white structure, the embryo, embedded in the hard endosperm, which is composed of cellulose. This is a compound of carbon, hydrogen, and oxygen, and during the germination of the seed is changed, by an enzyme, into soluble substances which enable the embryo to grow.

The radicle fits into the protuberance and the plumule is surrounded by the single cotyledon, which forms a sheath, the tip of which is in contact with the endosperm.

Soak some date-stones in water for two or three days, and then keep them in moist sawdust, which you can easily move aside to examine the seeds once a week. The radicle grows out first and is followed by the base of the sheath of the cotyledon pushing the radicle farther into the soil and arching, if necessary, so that the enclosed plumule is in a favourable position to grow out and up. The tip of the cotyledon never emerges, but remains in contact with the endosperm, absorbing the food solution, and passing it into the embryo. When the sheath is from one to two inches long, the plumule grows out from its folds, protected by another sheath which is really the first leaf. From within this may

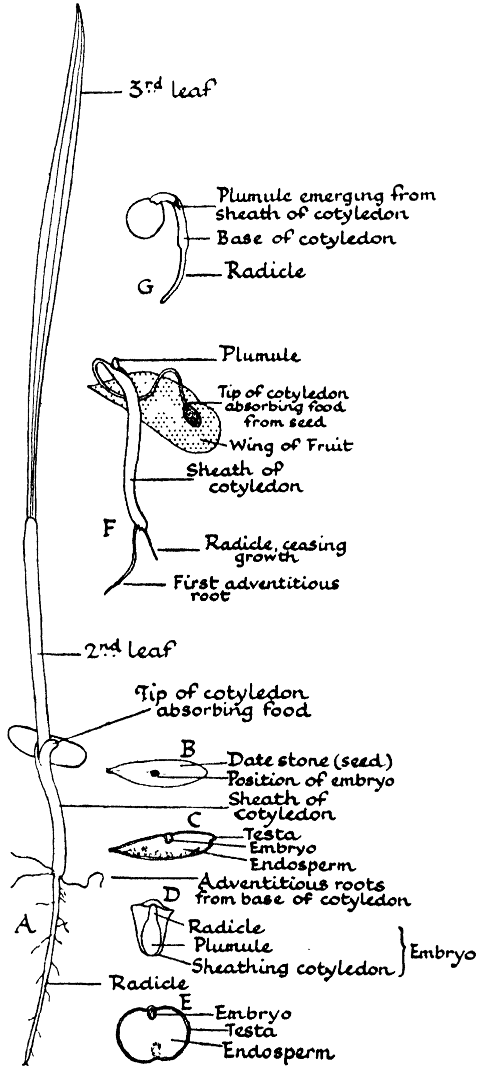


FIG. 28.

A–E. Germination of date.
C. Longitudinal section of seed. × ½.
D. Embryo removed from seed. × 3.
E. Transverse section of seed. × 1½.
F. Germination of gladiolus seed. × 1½.
G. Germination of bluebell seed. × 1½.

appear another simple sheathing leaf, or a long narrow leaf folded like a fan but pointed at the tip, so that when the folds spread out the leaf usually splits at the tip into two or three ribbon-like strips. Meanwhile several branches grow from the radicle and other roots grow from the base of the cotyledon. These adventitious roots usually grow very freely, while the growth of the radicle goes on very slowly and soon ceases. Thus a fibrous root system is formed.

Some other seeds which have only one cotyledon germinate in a rather different way, the entire cotyledon remaining

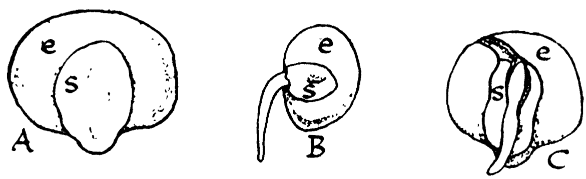


FIG. 29—GERMINATION OF MAIZE. × 1½.

A. Soaked fruit. Embryo visible through pericarp.
B, C. Emergence of radicle and plumule.
e, endosperm. *s*, cotyledon acting as absorbing organ.

within the seed and absorbing the dissolved endosperm for the use of the embryo. If you grow certain cereals, such as maize, you may watch this type of germination. It occurs in all grasses, but the fruits of most are so small that the structure of the seed and the stages of germination are extremely difficult to see, even with a good magnifying glass.

The single cotyledon of the bluebell, like that of the date, has a sheath which protects the plumule in its growth and bears adventitious roots at its base. The tip of the cotyledon remains within the seed. It would be interesting to discover whether bluebell seeds will start growth on cotton wool. Those described germinated in soil, and none of the seeds sown on cotton wool showed any sign of growth.

There are several outstanding differences between the sweet pea and the bluebell, and the most important of these are shown in the following table:—

	Sweet Pea	*Bluebell*
1.	Two cotyledons.	One cotyledon.
2.	True roots.	Adventitious roots.
3.	Tap root system.	Fibrous root system.
4.	Leaves net-veined.	Leaves with parallel veins.
5.	Leaves dorsiventral.	Leaves bifacial.
6.	Perianth parts in fives.	Perianth parts in threes.
7.	Twice five stamens.	Twice three stamens.
8.	One carpel.	Three carpels.

Those flowering plants which are Angiosperms [1] are divided into two classes, the **Dicotyledons** and the **Monocotyledons.** These names make it easy for you to put the sweet pea and bluebell into the class to which each belongs. Since the former has two cotyledons it is a Dicotyledon, while the bluebell with its single seed-leaf is a Monocotyledon. The other differences shown in the table usually help to distinguish the Monocotyledons; there are a few exceptions, so that it is not quite safe to say that a plant belongs to either class unless you know the number of cotyledons it has. The flowers of Dicotyledons differ considerably in their numbers of petals, sepals, and stamens. The arrangement in fives is most frequent, but smaller or larger numbers are very common.

The Scots Pine

During your walks look for cone-bearing trees, or conifers, and collect and compare different kinds of cones. The Scots pine is the conifer most frequently found in Great Britain and Northern Europe. It is a tall, straight tree, reaching a height of a hundred feet when it grows in good soil and has plenty of room. The diameter of its trunk varies and usually averages from two to three feet, but it may become four feet when growing under the best conditions. Put a piece of string round the trunk, and measure the girth of the trees you find.

[1] See page 12.

Notice the kind of soil in which the trees grow, the direction of the prevailing winds, whether the situation be exposed or sheltered, damp or dry. Try to discover the conditions which best suit the pine. The bark is dark grey, very rough, and sticky. It peels off in flakes, disclosing the red surface beneath. The first branches grow quite near the ground, so that the young pine is an easy tree to climb, though not a pleasant one on account of its extreme stickiness. This is due to the large amount of resin secreted by some of the cells. The lower branches are almost horizontal, but the top ones have an upward trend. The intermediate branches grow slightly upward at first, and then bend down, and the general effect of the tree is one of stiffness, and often of bareness, as the lowest branches soon die and break off.

Why should the bark split and gradually fall off? As the tree grows taller it needs more support, and also more cells to transport the food. The cells which carry the food to and from the leaves are mostly near the centre of the stem and around them in the young plant is most of the supporting tissue, arranged in a ring. New cells are formed by the division of the cambium, a ring of cells which divide very rapidly in spring, and much more slowly in autumn. The production of these new cells within the stem causes a tremendous strain on the outermost ones, which are eventually torn apart. While the strain is being produced, other cells, just beneath the bark, divide rapidly and produce a number of cork cells. The walls of these will not allow food solutions to pass through them, so when the bark tears, these new cork cells prevent the formation of a wound, and the consequent loss of food. Look at the cut surface of a pine log and count the number of rings you can see. Two of these represent a year's growth and are produced by the difference in appearance of the spring and autumn wood. The cells produced by the cambium in spring, when the sap is rising in the tree, are large and numerous, and have light brown walls. Those produced in autumn, when the sap is falling and growth is slow, are small and dark brown, so by counting the number of dark rings you can find the age of the tree. Running through the wood are a number of light streaks or rays. These are collections of living cells which pass among the dead supporting tissues and connect the living cells in the centre with those conducting the food solutions from the leaves and from the root. It is these rays which give wood its characteristic "grain".

The root is a strong tap root which usually grows deeply into the soil and sends out many branches to anchor the tree securely.

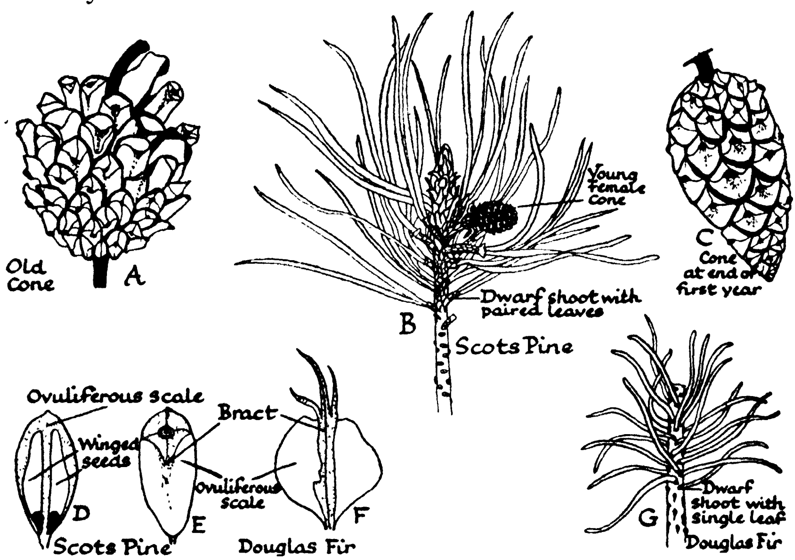


FIG. 30.

SCOTS PINE. A, B, C, × $\frac{1}{2}$; D, E, × $\frac{3}{4}$.
D. Ventral surface. E. Dorsal surface.
DOUGLAS FIR. F × $\frac{3}{4}$.
F. Dorsal surface of ovuliferous scale. G. × $\frac{1}{2}$.

The tough leaves are borne in pairs on very short branches growing in close spirals on the main branches. A pine can be distinguished from a fir by the arrangement of the leaves. With one exception, the leaves of pines arise in pairs or in clusters of three or five at the end of special short branches, the dwarf shoots, about one-tenth of an inch long. The leaves of firs always grow singly and arise on the main branches:

there are no special leaf-bearing shoots. You may see this if you examine a Christmas-tree, which is a young spruce fir.

The long pointed leaves of the Scots pine are spoken of as pine needles. They are almost semicircular in section and the slightly concave sides of the pair fit closely together when the young leaves are growing. They stay on the tree for two or three years, gradually changing their colour from a light bluish green to a very dark green. Since the leaves are not all shed at the same time the tree is evergreen.

With the leaves, the whole dwarf shoot is shed, and before this happens, layers of cells at its base become corky and stop the passage of food solutions. The shoot then drops off and its scar, formed by this corky layer or callus, may be seen on the main branch.

The bases of the dwarf shoots bear small brown scale leaves, and similar scales also grow on the main branches, or branches of unlimited growth, as they are called, because their growth may continue every year. Since the dwarf shoots are terminated by the leaves they cannot continue to grow, and on this account are branches of limited growth. The shoots of unlimited growth are each terminated by a small oval bud. This is covered by thin light-brown scales, and in the spring the axis of the bud grows, the scales separate, and the new dwarf shoots with the minute leaves can be seen. By the growth of this bud, some inches may be added to the branch every year.

In the axils of the lower scales, instead of dwarf shoots, tiny inflorescences, each shaped like a bud, may arise, and usually open in May. Examine one through a lens and you will be able to see a number of scales. With a pair of needles remove a scale and notice the anther attached to its lower surface. Each scale, then, may be regarded as a stamen. The anther is divided into two parts, each bursting to liberate large masses of pale yellow pollen resembling flowers of sulphur. Since these inflorescences contain only stamens they are known as male, while the cones bearing the ovules are female inflorescences.

The young cones arise in the axils of the upper scale leaves of the growing terminal bud, and usually on different branches from those bearing male inflorescences. Collect some young cones: notice that each is at the end of a dwarf shoot and consists of a number of small overlapping green scales arranged spirally round the axis. Growing on these scales and fused with them, so that the two are difficult to distinguish separately, is a scale which bears two minute brown ovules on its upper surface. This scale is described as the ovule-bearing scale, and the outer one as a bract. The scales spread out from the axis in June when the pollen is liberated, and may be blown on to the ovules, which hold it fast in a sticky fluid. The scales then close together again, forming a tight, compact cone which goes on growing, and may increase its length from rather less than half an inch in the autumn of one year to an inch and a half by that of the following one. In the summer of this year fertilisation usually takes place. Within the scales, the pollen grains rest for a time, and then as the sticky fluid dries up, they are drawn down into the ovule. The male nucleus is carried to the egg-cell by the growth of a tube from the pollen grain. The embryo then develops, and in the next year, the third year of growth, the scales open out from the axis and reveal the seeds. Each has a thin papery wing at its apex and by means of this the wind may carry the seed to some distance. When the seed germinates it produces an embryo with several cotyledons, sometimes as many as ten.

If you have collected the cones and noticed the arrangement and exposure of the seeds, you should be able to understand what is meant by a *Gymnosperm*, and why the Scots pine is included in that division of flowering plants. The pines, firs, cypresses and yews are the most commonly known *Gymnosperms*.

Let us now examine some of the plants which do not produce seeds. Of these we will consider types which you should be able to find without difficulty.

The Hart's Tongue Fern

You may find the most common species of hart's tongue on sheltered banks, where it may grow to a height of two feet.

Look at the rich green leaves or fronds. Notice that they are stalked and the leafy part is shaped like a long tongue, and often has somewhat frilled edges. The stalk or rachis (Gk. *rachis*, the spine) extends as a well marked mid-rib through the centre of the leafy part, and in the young frond bears a great number of tiny brown scales. On the older fronds scales are still visible, but in much smaller numbers. Many small parallel veins run from the mid-rib to the apparent margin, and along some of these, on the lower surface of the frond you may find long narrow green ridges which later become light brown and when fully ripe liberate a large number of minute dark brown spores. The membranous margin on either side of these spore-bearing masses is the true margin of the frond, but further growth has produced the expanse between this and the edge or false margin. This expanse enables the frond to take in more carbon dioxide and build it into food. On indoor ferns the spores may appear at almost any time of year, but on the outdoor specimens they are usually produced in late summer or autumn.

Without injuring any part of the fern, move away the earth from one side of it until you see a very dense mass of fine fibrous roots. Notice how these roots seem to be entangled round the bases of the fronds, so that it is difficult to find where they grow out from the underground stem. Move the roots carefully aside, and you will find that they grow just beneath the bases of the leaves, and are therefore adventitious.

The stem is short and thick, and grows slightly obliquely through the soil, so that every year it grows nearer the surface and finally may appear above the ground. Below the fronds it is closely beset with rather stiff brown curved structures which are the bases of old fronds.

The underground stem is called a rhizome (Gk. *rhiza*, a root), because at first sight it resembles a root. However, no root bears leaves and buds, and as the rhizome bears both it must be a stem. Near its tip you may find some very young coiled fronds. Notice how in growing through the earth they uncoil gradually before they finally straighten above the surface. On this account they are much less likely to be injured than they would be if the delicate tip of the frond had to push its way through.

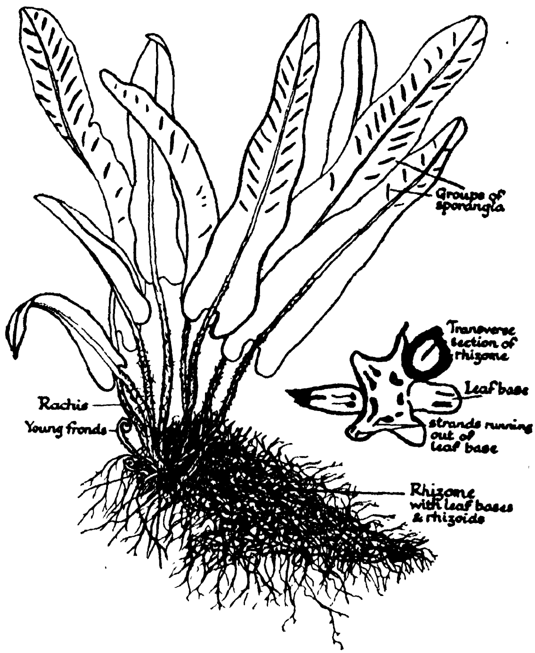


FIG. 31.—HART'S TONGUE FERN. × ¼

Cut an old rhizome and look at the cut surface. You will see brown patches and strands of various sizes, and will be able to trace some of these running through the leaf bases. The smaller ones will run out to the leaves above the cut. These strands provide the food channels to convey solutions from the roots, and the food built by the leaves, to other parts of the plant.

If the spores be ripe, shake some off and try to grow them on damp blotting-paper. Look on the ground beneath the fronds and try to find some small green heart-shaped plants growing flat on the soil. The spores germinate usually within a week or two after they are shed, and form the small gametophyte, which is usually about half an inch across and fixed in the soil by tiny rhizoids.

You have read how the seeds of the sweet pea are formed by the union of part of the pollen grain with the egg-cell contained in the ovule. The fern, a flowerless plant, produces no pollen and no ovules, but on the gametophyte the parts that correspond to these develop, but are much too small to be seen except under the microscope. The egg-cell is produced on the gametophyte and fertilisation is accomplished by a minute cell, called a spermatozoid, swimming through drops of dew or rain to an egg-cell and fusing with it. From this single fertilised egg-cell the new spore-bearing plant or sporophyte grows up. The difference between a spore and a seed is that the latter always contains an embryo, whereas this structure is never developed in a spore. As in animals, the egg-cell is described as a female cell and the spermatozoid as a male cell.

The plant may also be reproduced by buds of the rhizome growing into branches bearing other plants. This form of reproduction is described as vegetative.

A Liverwort—*Marchantia*

You may find this plant growing on the banks of sheltered streams. It forms broad stretches of a flat green thallus which forks repeatedly, so that it grows in all directions. Extending from the notch in each branch of the thallus is a well marked depression, the mid-rib, which forms a ridge on the lower surface.

The upper surface is marked into small diamond-shaped areas, and in the centre of each is a minute pore which opens into an air chamber beneath. The grooves separating the areas show where columns of cells form the walls of the air-chambers, the upper surface of the thallus forming the roofs.

Remove a small piece of the thallus and examine its lower surface. This is lighter in colour, and on the mid-rib are several rhizoids and some overlapping violet scales. There may be a few scattered on other parts of the thallus, and

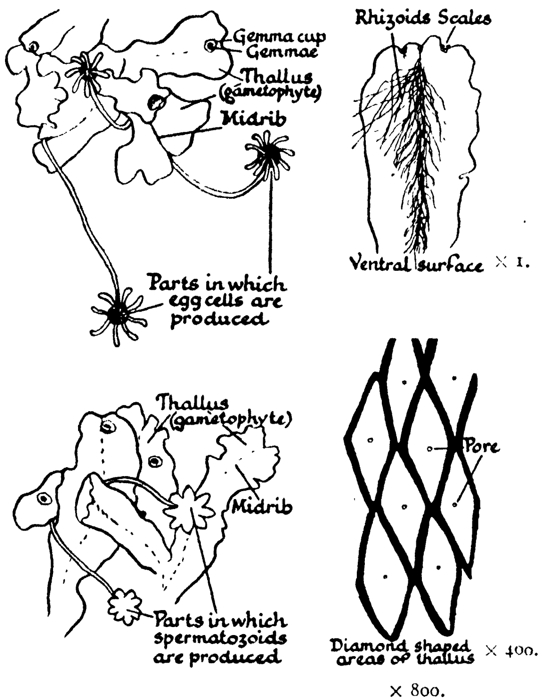


FIG. 32.—*MARCHANTIA*. × ½.

some of the scales protect the growing point which lies in each notch of the thallus.

You may find on the upper or dorsal surface some small cups containing tiny green structures. Carefully remove a few of these with a blunt needle and float them in a drop of water on a piece of glass resting on a white paper. You may then separate them and grow them on damp soil, for each of these tiny flat bodies, or gemmæ, will, under favourable conditions, grow into a new plant. Some cells of a gemma produce rhizoids, while others build up food and divide to form the thallus.

In May or June you may find stalks growing from the notches of the thallus. Some of these stalks bear flat disc-like heads, others have heads with rays like the ribs of an umbrella. Sunk in the disc-shaped heads are special structures which produce spermatozoids, and these swim through drops of water formed by dew or rain, or by the splashing of the stream, to the ray-shaped heads. Here, growing in a ventral cushion of tissue between the rays, are numerous structures bearing egg-cells. A spermatozoid fuses with an egg-cell and fertilises it.

Since the thallus of *Marchantia* bears the gametes it is the gametophyte. The sporophyte is very poorly developed, growing within the structure which contained the egg-cell. The fertilised egg-cell divides repeatedly, and produces a capsule containing a large number of spores. When these are ripe the tiny stalk of the capsule grows sufficiently to push it through the surface, so that in July it may be seen on the under surface of the head. The wall of the capsule splits into a number of teeth and a mass of bright yellow spores is set free. These spores often remain in tufts on the head, especially if the air be damp. In dry weather the spores are blown away by the wind.

Collect some of the spores and keep them on moist blotting-paper. They first produce a very minute green thread which grows out at one side of the tip to produce a new thallus.

After the spores are shed the older parts of the thallus die, and the tips of the branches carry on the growth in the following spring.

Some other liverworts such as *Pellia*, which is very common in the south of England, have no diamond-shaped areas, produce no gemmæ, and produce the gametes in structures sunken in the thallus. The sporophyte of *Pellia* is a dark green capsule about a tenth of an inch in diameter, borne on a long pale green stalk, and is consequently much more easily seen than the sporophyte of *Marchantia.*

Although in these respects liverworts differ considerably, the plant thallus is always the gametophyte, the sporophyte always grows from it, and the generations always alternate.

A Moss—*Funaria*

You will find this moss growing on damp walls and on soil.

It has a short, erect stem with numerous rhizoids growing from its base. The young rhizoids are colourless, but they soon become dark brown.

The leaves are arranged spirally on the stem, are dark green and very thin. As in the liverwort, the moss plant is the gametophyte, but it differs from *Marchantia* in producing separate male and female gametophytes.

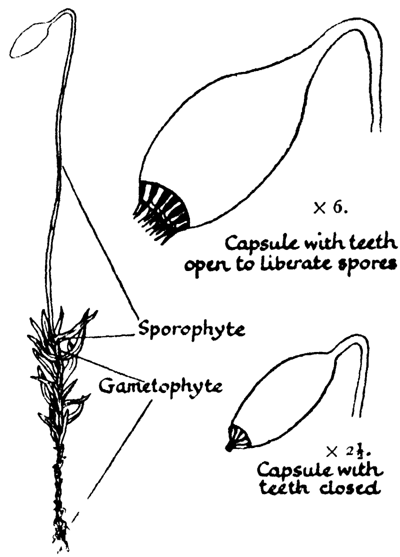


FIG. 33.—MOSS PLANT. × 2.

Look for specimens of *Funaria* about half an inch high, or rather less, and having bright red tips. These are the male plants, and if you flatten out the red bud in water on a slide and examine it under the microscope you may be able to see spermatozoids escaping from flattened oval structures. Between these are green filaments.

The female plants are not so easily found until they bear the capsules. When producing egg-cells the female plant may be only one or two tenths of an inch high, and has no red bud to distinguish it. If you find a female plant, flatten out the tip in water, examine it under the microscope and look for narrow flask-shaped structures. In each of these an egg-cell is produced and may be fertilised by a spermatozoid which has reached it by swimming through rain or dewdrops to the tip of the female plant.

The fertilised egg-cell divides, producing a capsule in which the spores are formed, and a slender stalk which grows rapidly, forcing the capsule to burst the surrounding wall and to carry up the top part as a brown cap which eventually drops off. In the gametophyte the stalk is firmly embedded by its fleshy base, which absorbs the food solutions. The barrel-shaped capsule is green, and can build food from the carbon dioxide from the air. When the spores are ripe, several minute brown teeth are formed in two rows at the tip of the capsule and separate in dry weather, allowing the spores to be blown and shaken out. In wet weather these teeth absorb water, swell, and close the capsule. You will find it quite interesting to watch, through a good hand lens, the movements of the teeth.

Collect some of the spores and spread them on damp blotting-paper laid on the surface of soil. The germinating spore produces a much-branched hair-like structure, the protonema, and from buds of this new moss gametophytes grow.

Although *Funaria* rarely branches, some other mosses frequently are branched. A curious thing to notice is that in mosses each branch grows *beneath* a leaf instead of in its axil, as in flowering plants.

Fungi—The Mushroom and Moulds

You may find the mushroom growing in open fields and pasture land in late summer and early autumn, especially after rain or heavy dews.

When gathering mushrooms, always cut them, for in pulling them up you may remove all the parts of the plant, and so make it impossible for more to grow.

Since the plant has no chlorophyll it is unable to build up food from carbon dioxide and solutions of mineral salts: so it obtains its complex foods from the decaying vegetable matter in the soil.

Underneath the soil, the fungus grows as a tangle of very fine colourless threads or hyphæ. These interweave to form a tiny compact mass appearing above the soil as a white spherical head which grows so rapidly that in a few hours it has developed a stalk, or stipe, and a head, or pileus (L. *pileus*, a felt cap). If you cut the young mushroom longitudinally before the head has expanded, you may find the tough, white upper part of the cap, and, around the stalk, some delicate pale pink fleshy plates or gills hanging down in a small cavity or gill chamber. Across the floor of this chamber is stretched a white skin or veil, the velum. By the rapid growth of the head, the veil is torn, leaving ragged margins round the stalk and round the edge of the cap.

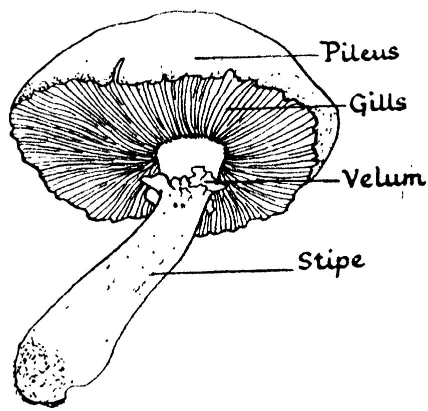


FIG. 34.—MUSHROOM. × ⅝.

Take hold of this latter margin and notice how easily you can remove the skin from the cap. Notice that the stalk is more spongy than the head.

The gills darken with age, changing from very pale pink to dark brownish grey, eventually becoming almost black.

Put a black head on a sheet of white paper, leave it for a few minutes and then lift it straight up. Masses of spores should have been deposited along the lines where the gills rested. The spores are very minute and grow all over the surface of the gills from special cells, each of which produces four spores. When ripe, these drop off and may be distributed by the wind.

The spores germinate and grow very slowly into the thread-like hyphæ. Blocks of soil and manure permeated with these may be bought from seedsmen as mushroom "spawn". If you pull up mushrooms instead of cutting them you will remove large numbers of hyphæ from the soil, so that fewer mushrooms can be produced.

Mushrooms and toadstools form spores only: there is no gametophyte.

All the fungi consist of hyphæ: some, like the mushroom, have compact fruit bodies formed by interwoven hyphæ; others, like the mould on cheese, produce their spores on minute branches of the hypha.

A blue mould found on jam, the vine mildew, and some other fungi produce gametes which fuse, and then develop into a fruit body containing the spores, but the whole plants

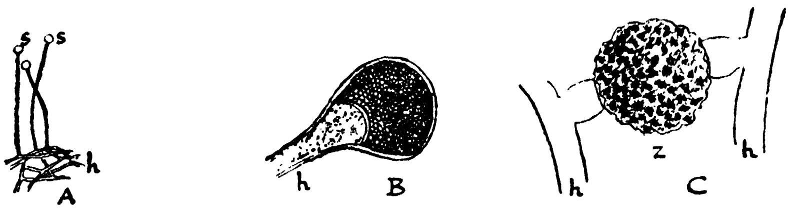


FIG. 35. A SPECIES OF *MUCOR*.

A. Mycelium with sporangia (magnified)
B. Sporangium filled with spores (much magnified)
C. Zygospore. × 200.

h, Hypha.
s, Sporangium.
z, Zygospore.

are so small that, without the aid of a microscope, you will be unable to find the parts producing the gametes.

One of the commonest of these small fungi is *Mucor*, and you may find this on stale bread, where its hyphæ form a white fluffy mass. It grows also on fruit juices, jam, and many other foods. How does the plant get on the food? Keep some stale bread moist and exposed to the air, and most probably, sooner or later, *Mucor* will appear on it. Look at the fungus daily and you will find small black heads grow at the tips of some of the hyphæ, which then look like tiny black-headed pins. Within the heads are countless minute colourless spores, and these, when ripe, are shot out by the pressure of the liquid in the central part of the head bursting the outer wall. The spores, invisible to the naked eye, float in the air for some time and are easily carried about by any air current. When a spore settles on a suitable food substance, it grows into a small hypha which branches repeatedly, some branches passing down into the food, while others grow into the air. Often the rooting branches become brown, and one species of *Mucor* also has brown aerial hyphæ.

Occasionally you may find other black specks on the mould. These usually lie nearer the surface of the food material than those already described, and each has been formed by the union of the tips of two hyphæ or branches. From each of these tips a cell is cut off, and in it the gametes develop and fuse in pairs after the tips unite. The cell containing the fused gametes receives large food stores, becomes surrounded by a very thick protective wall, usually dark brown or black, and can survive unfavourable conditions for a considerable time, often for several months. This cell is sometimes spoken of as a resting spore, and since it results from the fusion of gametes, it is a zygospore.[1] When this is provided with food and kept at a suitable temperature, one or more hyphæ grow from it. These branch, under favourable conditions, and soon produce masses of hyphæ; if conditions be unfavourable, the tip of a hypha may produce a mass of ordinary spores which may be carried to a more suitable place.

From the study of *Mucor*, you will see that there is no distinction between the gametophyte and sporophyte, as there is in the other flowerless plants you have examined, and this is true of all fungi which produce gametes.

The following scheme for the study of a plant is suggested to help you to carry out your examination in an orderly way, so that your observations will be more likely to be as complete and accurate as you can make them.

[1] Compare this with the zygospore of *Spirogyra*.

PRACTICAL WORK

Habitat.

Is the plant terrestrial (on land), *or aquatic* (in water)? If terrestrial, on what kind of soil does it grow? Is it shaded or exposed to the sun? Notice the kind of plants growing with it. If aquatic, is it in fresh, running, or stagnant, or in salt water? Is it always submerged? Does it grow in deep or shallow water?

Habit.

Is the plant a tree, a shrub, or a herb, or has it a thallus which is not divided into a leafy shoot and root? Does it grow erect, or climb, or creep over the ground? Is it fixed or floating?

General Appearance.

Estimate the size of the plant.

If branches be present, are they numerous or few? How are they arranged, and in what direction do they grow?

If the plant have a thallus, describe its form—is it thread-like (filamentous), or flattened and dorsiventral, as in most liverworts, or mushroom-like? Has it a holdfast or rhizoids?

Root.

Is there a tap—or fibrous—root system? Do the roots grow deeply into the soil or near the surface? Do they store food? Have they few or many branches, and are there any root hairs? Note and sketch the direction of growth of the branches. Are tubercles present?

If there be a holdfast or rhizoids instead of a root, describe these structures as completely as you can and sketch them.

Stem.

Estimate its length.

Is it erect, creeping, or climbing? Is it branched or unbranched? If branched, note whether branches be few or many. Sketch their arrangement on the main stem, and the direction of their growth. Branching may be either racemose (grape-like) or cymose (Gk. *kyma*, a sprout). In the racemose form the main axis continues its growth indefinitely and sends out lateral branches as it grows, the youngest branch being near the tip. In the cymose form, the growth of the main axis becomes slow and the bud, or buds, lying behind the terminal one, continue

[1] Botanical specimens may be obtained from Miss Nora Legg, Selborne, Hants.

the growth, so the terminal bud may be turned aside, and grow to resemble a lateral branch. Since branches always arise in the axils of leaves you may easily distinguish a raceme from a cyme, for in the latter the bud which has been pushed aside is opposite a leaf, and from the axil so formed grows the branch which is the main axis, as the diagram shows. This branch in turn is pushed aside by the vigorous growth of its lateral bud or buds. Sometimes the buds are pushed alternately right and left, so that in older plants the branching looks

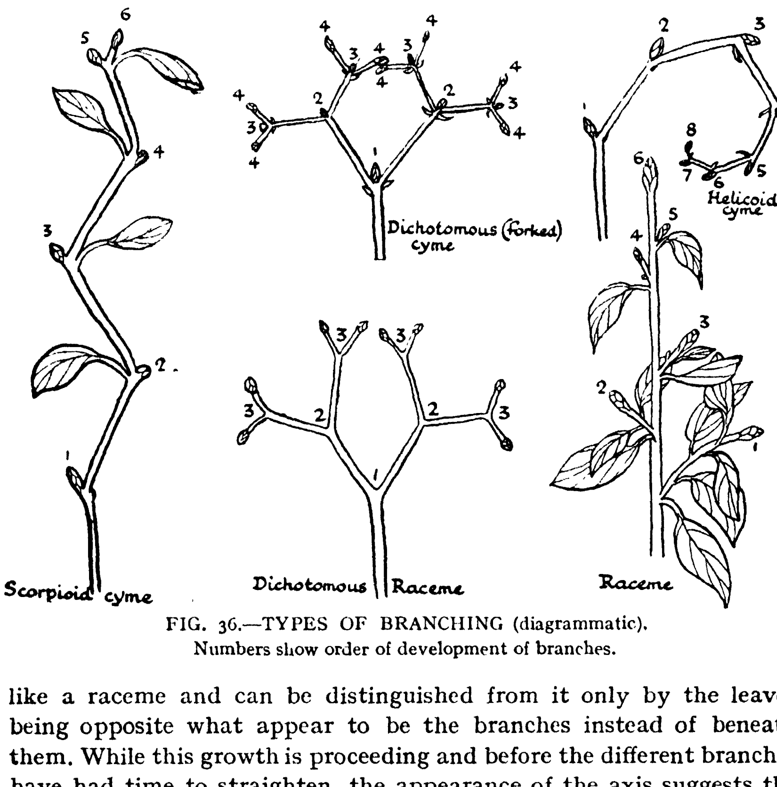


FIG. 36.—TYPES OF BRANCHING (diagrammatic). Numbers show order of development of branches.

like a raceme and can be distinguished from it only by the leaves being opposite what appear to be the branches instead of beneath them. While this growth is proceeding and before the different branches have had time to straighten, the appearance of the axis suggests the undulating movements of a snake or scorpion, and so this form of cyme is described as scorpioid. The beech-tree and lilac show it quite well. If all the terminal buds be pushed aside in the same direction the young shoot is coiled like a snail's shell, and is helicoid (Gk *helix*, a spiral).

If the plant be a tree, try to estimate the height of the bole—the unbranched part of the trunk—as well as of the whole trunk. You may do this by comparing it with your own height, or better, by means of a clinometer, such as you may have made in your geography lessons or in connection with Scouts' or Guides' Troops. Does the bole fork? Is the bark thick or thin, rough or smooth? Does it peel off in rough irregular pieces or in fairly large thin flakes?

If the plant be a shrub, note whether the branches be tough and flexible, or inflexible.

On young, woody branches, such as those of shrubs and the leafy branches of trees, look for small light-coloured patches. These are the

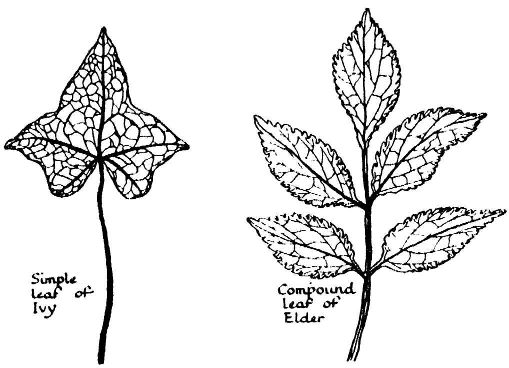


FIG. 37.—TYPES OF LEAVES. × ⅓.

lenticels, and consist of groups of cells with air spaces between them, so that oxygen can pass in and carbon dioxide out of the plant, which cannot breathe through the thick rind formed over these branches.

Smaller plants which are not woody enough to be described as shrubs are called herbs. Note the shape of the stem, the thickness of the skin, and whether it be rough or smooth. Describe the form and arrangement of hairs if any be present.

Try to find the age of a branch by counting the number of ring-like scars on the stem. The branch is terminated by a bud, which is protected by scale leaves during the winter. When the bud begins to grow, the scale leaves fall off and a ring of scars is formed. This happens every year, so the distance between two scar rings shows a year's growth.

Cut the stem transversely, and describe what you see.

Leaves.

Draw a leaf and show the direction of its veins. Is the leaf simple or compound: dorsiventral or bifacial? Is its margin entire, or lobed, or serrated? Note the colour of the leaf and whether the surface be dull or glossy, rough, hairy, or smooth. If the two surfaces differ, describe the differences.

How are the leaves arranged on the stem? Have they petioles? If so, describe their shape. Are stipules present?

Notice the plant when the light falls on it. Are any leaves so arranged that they receive no light?

Inflorescence (only in flowering plants).

Is it solitary (like the tulip), *racemose,* or *cymose?* Draw a simple diagram to show the arrangement of the flowers, and note the positions of the oldest and youngest ones.

Flowers arranged in a head as in the daisy and dandelion form a capitulum (L. *caput,* the head). Those arising from the same level, like the ribs inside an umbrella, as in the carrot and parsley, form an umbel (L. *umbella,* a little shade).

Is the entire inflorescence protected by special leaves or bracts, as in the daffodil, hazel, and dandelion? If so, describe their general appearance, and note whether there be few or many.

Flower.

Note the colour, size, shape, and smell. If the segments be equal, as in the primrose, the flower is regular: if they be unequal, it is irregular, as in the violet.

Are perianth, stamens, and pistil all present? If so, the flower is complete. If any parts be missing it is incomplete. When the flower has stamens but no pistil, as in the "lamb's tail" catkins of hazel, it is described as male. A flower having a pistil but no stamens, as in the bud-like inflorescence of hazel, is female. If both pistil and stamens be present, it is hermaphrodite. The positions of the parts of the flowers are described in relation to the pistil or gynæcium. When the parts arise below it, as in the primrose, they are hypogynous (Gk. *hypo,* under; *gyne,* female); when around the gynæcium, and on the same level, as in the rose, the parts are perigynous (Gk. *peri,* around), and if above it they are epigynous (Gk. *epi,* upon). By looking at the diagrams you may see how these differences in position probably arose. The tip of the flower stalk of the bluebell forms a swollen receptacle on which the pistil grows at the top, and the perianth segments below, so that they are hypogynous.

Now imagine that it is possible to compress the flower, flattening the receptacle and spreading the pistil, stamens, and perianth segments on the same level, so that the parts are perigynous. This flattened receptacle may be curved up, as in the rose, but since all the parts were formed on the same level they are still described as perigynous. Carry your imagination a step further, and suppose that the receptacle, instead of being flattened, were pushed inwards so that the tip with the pistil lay in a hollow, and the sides of the receptacle grew together, enclosing this cavity and carrying the stamens and perianth on top, so making them epigynous, as in the parsley and daffodil.

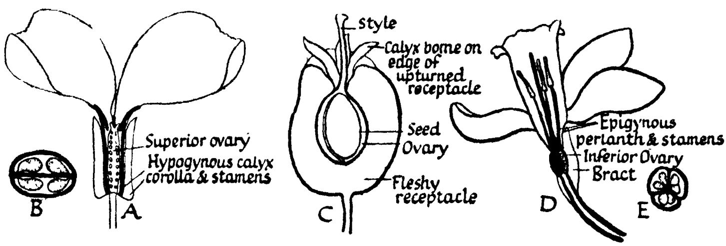


FIG. 38.

WALLFLOWER. × ¼. A. Half-flower to show hypogyny. B. Cross-section of ovary showing parietal placentation of ovules. × 7½.

HAWTHORN. × 1½. C. Half-fruit with remains of flower showing perigyny.

DAFFODIL. × ¼. D. Half-flower to show epigyny. E. Cross-section of ovary showing axile placentation. × 1.

Perianth.

Is it divided into a distinct calyx and corolla as in the primrose, or are all the segments alike, as in the bluebell and daffodil?

Sketch the parts. Are they free or joined?

Describe the colour and arrangement of the segments and their position.

Calyx.

How many sepals are there? Are they free or joined, hypo-, peri-, or epi-gynous? Do they secrete or hold nectar? What are their uses?

Corolla.

Count the petals and describe them in the same way as the sepals. What are the uses of the corolla?

Andrœcium.

How many stamens are there? Are they free or joined to the petals? Are their filaments separate or joined? Are the anthers free or connected?

Sketch the andrœcium and also a single stamen showing how the anther is joined to the filament and how it bursts to liberate the pollen. Of what colour is the pollen? Does it seem powdery and dry, or sticky? How is it transferred to the stigmas of other flowers?

Gynæcium.

How many pistils are there in a single flower?

Sketch one pistil, note how many styles and stigmas it has, and their shape and colour. Is the style longer or shorter than the stamens, or equal in length to them?

The ovary is described as superior or inferior, according to its position respectively above or below the other parts of the flower.

Cut the ovary transversely and find how many compartments it has. Note the number and sketch the arrangement of the ovules. If the ovules grow from the walls of the ovary, as in the poppy, they are said to have parietal placentation (L. *parietis*, a wall); if they grow from the central angles of the compartments, as in the bluebell, the placentation is axile, and if, as in the primrose, they grow on a central pillar arising from the base of the ovary, and not connected with its walls, the placentation is free central.

Fruit.

Sketch the fruit and name all the parts.

Find out how the seeds are shed.

Seeds.

Note their colour, size, number, and shape. Are they rough, smooth, or hairy; heavy or light?

How many cotyledons are there? Is endosperm present?

Try to grow the seeds and watch the behaviour of the cotyledons.

Non-Flowering Plants.

After describing the roots and shoots or the thallus try to find where the plant produces its spores, and how they are liberated. Sketch any special spore-producing parts. Try to grow some of the spores and discover whether they grow directly into a plant like the sporophyte you have examined, or whether they produce a gametophyte.

If the plant be a fungus, handle it carefully and wash your hands before touching your mouth, nose, or any food, as many toadstools are very poisonous, especially those which have a little cup at the base of the stalk. Note whether the stalk is smooth, or whether there is a ragged ring towards the head. Try to account for the presence of such a ring.

Observe the colour of the head. If it be bright, the fungus is probably poisonous. Is the upper surface rough or smooth; clear and shiny, or flecked with spots of colour or patches of skin? Can the skin be peeled off easily?

Are there gills or pores on the lower surface?

If the spores be coloured, try to get a print of them by leaving the head, gills or pores downwards, for about twenty minutes on a clean sheet of paper. Then lift the head straight up without smearing it across the paper.

Try to find out how the spores are liberated and distributed.

Many fungi are not divided into head and stalk like the mushrooms and toadstools. Some consist merely of interwoven threads; others form beautiful cup-shaped bodies like the crimson ones you may find on hàzel, or the yellowish waxen ones on soil, in beech woods, but all produce spores, and in most cases you should be able to discover where they are produced, and how they are dispersed.

ADDITIONAL PRACTICAL WORK

In the manner described in this chapter describe the following plants:—

1. Broad Bean
2. Vetch
3. Broom
4. Gorse
5. Whin
6. Lupin
7. Buttercup
8. Anemone
9. Lesser celandine
10. Clematis
11. Water crowfoot
12. Primrose
13. Cowslip
14. Scarlet pimpernel
15. Lily of the valley
16. Hyacinth
17. Tulip
18. Foxglove
19. Snapdragon
20. Speedwell (*Veronica*)
21. Wild rose
22. Cherry
23. Apple
24. Plum
25. Iris
26. Crocus
27. Heather
28. Rhododendron
29. Azalea
30. Ling
31. Dead-nettle
32. Sage
33. Thyme
34. Mint
35. Daffodil
36. Narcissus
37. Snowdrop
38. Violet

39. Pansy
40. Sunflower
41. Dandelion
42. Marguerite
43. Daisy
44. Cornflower
45. Groundsel
46. Wallflower
47. Virginia stock
48. Honesty
49. Poppy
50. Honeysuckle
51. Willow-herb
52. Bindweed
53. Cow-parsnip
54. Carrot
55. Chervil
56. Willow
57. Poplar
58. Hazel
59. Holly
60. Horse chestnut
61. Plane
62. Lime
63. Beech
64. Sycamore
65. Oak
66. Common ash
67. Common elm
68. Elder
69. Alder
70. Silver birch
71. Laurel
72. Cedar
73. Christmas-tree (spruce fir)
74. Cypress
75. Yew
76. Bracken
77. Maidenhair fern
78. Male fern
79. *Polypodium*
80. Bladder-wrack
81. Ribbon seaweed (*Laminaria*)
82. Sea-lettuce
83. Any moss
84. Any liverwort
85. A toadstool

86. Fold a sheet of paper into four equal parts. Draw on the top part the shape of a simple leaf such as that of lilac and cut round the outline through the four thicknesses. Use these pieces to represent carpels, and by gumming the edges together represent the formation of the ovary of each of the following flowers: sweet pea, bluebell, violet.

87. Draw the buds of beech, horse chestnut, ash, and oak.

88. Examine the scars on a horse chestnut branch and try to account for the "nail prints".

89. Tennyson writes about "This yew-tree's smoke". Study the yew in late spring and early summer and try to find out what the "smoke" is.

90. Examine the cut trunks of as many trees as you can, and find out the age of the tree. Notice the "rays" or "grain" of the wood, and sketch the section of the trunk.

91. Sketch the leaves of hazel and alder. What are the differences between the two plants?

92. Make a list of the differences between the bark of beech and of plane.

93. Make sketches showing how the following plants shed their seeds: poppy, violet, pea, foxglove, primrose, horse chestnut, and Scots pine.

94. If you sit by fruiting gorse bushes on a hot day you may often hear a crackling noise. Watch the bushes and find out how the noise is made.

95. Plant a sycamore seed and draw the first two leaves to appear. Compare these leaves with the leaves on a full-grown tree.

96. Draw branches of ash, elm, and oak, and show the age of each branch.

97. Collect as many different kinds of moss capsules as you can. Draw large diagrams of them, and show how the spores are liberated.

98. Collect and draw pine and fir cones in different stages of their development. Say whether each cone is in its first, second or third year of growth.

EXERCISES AND QUESTIONS

1. Which of the flowers you have studied seem very much alike? Make a list of the ways in which they resemble one another, and of the ways in which they differ.

2. Make a list of six flowers you have studied which produce nectar. Make a sketch of each showing where the nectar is stored. Of what use is nectar to a flower?

3. How is pollen transferred in each case to the stigmas of hazel, poplar, willow, sweet pea, iris, bluebell?

4. Which of the flowers you have studied are visited by bees? Explain fully, with the aid of diagrams, how the bee gets what it wants from one of these flowers. How does the bee help the flower?

5. Which of the plants you have studied have very tough leaves? Rule two columns: in one put the name of the plant, in the other its habitat. Is there any connection between the toughness of the leaves and the nature of the habitat? If so, try to account for it.

6. Make a list of the evergreen plants you have examined. How do "evergreens" differ from other trees and shrubs in the way they shed their leaves?

7. Make sketches showing how the leaves of bracken unfold. Why should they unfold in this way?

8. What uses to the plant can you suggest for the hairs and scales found on most ferns?

9. Why does more and more of the rhizome of the male fern appear above the ground every year? How does it manage to do this?

10. What is a gametophyte? Name some plants having gametophytes which usually escape notice.

11. What is a sporophyte? Name a plant in which the sporophyte is very well developed, and another in which it is very little developed.

12. Where are the spores produced in the following plants, and how

are they liberated: *Marchantia*, bracken, *Funaria*, mushroom, and puff-ball?

13. The plant can produce only a certain amount of supporting tissue. This might be arranged to form a solid rod in the centre of the stem, or a ring lying between the centre and circumference, or a thinner ring round the outside. Try to explain why the second arrangement suggested is the one always found in plants.

14. What are the differences between a Gymnosperm and an Angiosperm?

15. Name two different divisions of plants which have an alternation of generations. Compare and contrast the gametophytes of each division.

16. Compare and contrast the dwarf shoots of a pine with a cabbage.

17. Which trees have you found with their roots growing near the surface of the soil? Name any plants you have found growing beneath these trees.

18. Which trees do you know to be deeply rooted? What plants grow beneath them?

19. Where have you found mosses growing alone? Why were no other plants found growing with the moss?

CHAPTER VI

HOW TO KEEP AN AQUARIUM

BEFORE keeping an aquarium (L. *aqua*, water) it is necessary to find which animals can be kept in captivity without injury, to know something about their habits, and especially their food. It is also wise to find out which creatures will live together without injuring one another. For instance, the great water beetle, which is quite common in ponds and lakes, will devour many of the inhabitants of the aquarium, and you must keep it alone if you want to observe it. You must also find out which plants will grow in standing water, and what they need for growth.

At first, collect animals and plants which live in still water. Those collected from running water can be kept successfully only in an aquarium fitted with a tap or waste pipe. Start your collection in a large pie-dish or bowl; any shallow vessel with a large opening will serve the purpose. A jam-jar should not be used, except as a temporary home for creatures which will be transferred later on to a larger vessel. The bowls sold for keeping goldfish are very unsuitable: the curved surface reflects light in a way harmful to the inmates, and the opening is far too small.

You can make a collecting net by covering the wire of an ordinary butterfly net, on a long handle, with a piece of fine cotton material, such as lawn, or, better still, with silk, in the centre of which a small hole has been cut. Through this hole fix the neck of a tiny bottle with a rim, and fasten the material round it tightly with thread or fine string. By this means you can catch plants and large insects, while the water which drains down into the tube may contain small creatures which would otherwise escape. When collecting, place the water weeds and animals with a little water in jars to carry home. Take care to keep different kinds in separate jars till you have found out whether they are friends or enemies.

Prepare some dishes before collecting. See that they are clean, and try to make them as much as possible like the natural homes of the living things you are going to keep in them. Cover the bottom of each with a mixture of sand and stones: use silver sand mixed with bird sand, which you can buy at the corn chandler's. Wash it well by putting it in a dish filled with water. Stir, allow the sand to settle, and pour off the water. Repeat this three or four times, or until the sand is free from dust and other impurities. Put it in your dishes, together with a few stones, and cover with pond or rain water. Keep only a few of each of two or three kinds of plants or animals in one dish: this will help you to find which will live together.

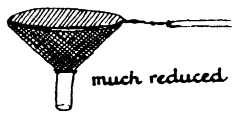


FIG. 39.—FISHING-NET WITH TUBE.

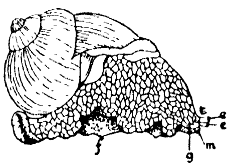
Later, when you can keep a large aquarium, you may be able to get an empty accumulator cell, or a large glass tank from a bird-dealer's. The aquarium need not be made of glass, although this is better, as you can then more easily observe the occupants. A large metal bowl or small bath will do, provided that it be enamelled. Scrub it out well, and place in it a layer of garden soil to a depth of about two inches, cover with an equal depth of sand, and add stones of different sizes. Cover the sand with a sheet of cardboard or strong paper, and then use a watering-can with a spray to pour in the water. Remove the cardboard when you have finished, and the water will be clear. Keep the aquarium on a wide window-sill or table near the light, but not exposed to strong sunlight. If the light be too strong, cover the glass sides with green paper.

A visit to any pond will show you that there are both plants and animals living in it. Many of the animals feed on the plants, while others are **carnivorous**; that is, they eat animal food. The plants themselves prepare their food from certain substances in the water and the air. If a pond contained only plants, it might in time become overstocked with them, and thus the plants would not have space to grow. On the other hand, in a pond containing only animals, there would probably be some vegetarians, unable to exist without plants. Moreover, in feeding, the plants set free oxygen, which is available for breathing; while the animals help to provide them with a certain amount of carbon dioxide for food.

Some of the smaller plants to be found in most ponds are duckweed, which floats on the surface, Canadian pondweed, and *Spirogyra*. All these you will be able to keep in your dishes, while in a larger aquarium you may keep plants like mare's tail, water crowfoot, and water plantain. When putting Canadian pondweed in the dishes, tie pieces carefully with bast to stones and drop them into the sand. Bast is used by gardeners for tying plants, and you can buy it at a florist's. The larger plants must be lifted out of the pond, without injuring the roots, and planted directly in the soil at the bottom of the aquarium, or in tiny flower-pots which can be placed in the soil and covered with sand. When you cannot get other plants, put water cress in the dishes: caddis-worms, especially, will eat it greedily.

On your water weeds you will probably find two kinds of water snail, the "trumpet" and the "ram's horn". Put some in each aquarium, for, as they feed on decaying plants and animals, they help to remove these and keep the water pure. Watch the water snail as it moves over the surface of the aquarium. The part of its body by means of which it glides along is called the "foot". Try to find the four tentacles and the mouth, just anterior to the foot. Each of the longer tentacles bears at its tip a black spot, the eye. This can be withdrawn for protection in the same way as the finger of a glove can be turned in by a piece of cotton attached inside to the tip.

Between the soft body and the lining of the shell is the mantle cavity, which is continually filled with air and emptied again by the drawing in and out of the body. In this way the snail breathes. Notice that occasionally it rises to the surface of the water and then sinks again. Watch carefully, and you will discover how it does this. Put a snail in a white dish or saucer with a little water, and examine the shell. It may twist spirally in a right-handed or a left-handed direction. As the snail grows, it adds to the shell at the free end or "lip", and at the same time the body inside grows and fills the extra space. The beginning of each addition to the shell is marked by a ridge, and the space between one ridge and the next will show how much growth takes place at a time.



ROMAN SNAIL. $\times \frac{1}{3}$.

f, Foot; *t*, Tentacles; *m*, Mouth; *e*, Eyes; *g*, Opening of reproductive organs.

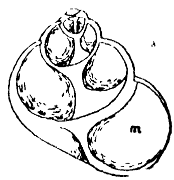
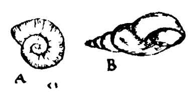


FIG. 40.

ROMAN SNAIL SHELL IN SECTION.

m, Mouth of shell.



SNAIL SHELLS. $\times \frac{1}{3}$.

A. Ramshorn. B. Trumpet.

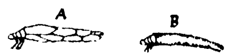
If you could cut an empty shell in two, you would see the spiral compartment within (Fig. 40).

The eggs are laid several together in a mass of jelly on the glass of the aquarium. Is the young snail able to look after itself? Place one or two in a saucer with a little water and look at them with the help of a lens: count the spirals of the shell. In most of your dishes snails can be kept, since they will not interfere with the other inhabitants.

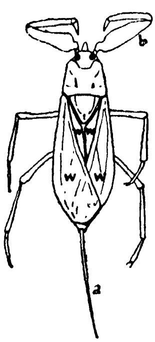
WATER BEETLES.

You will find several kinds of water beetles, most of which need to be kept separately. The **water boatman** is easily recognised by its method of rowing on its back in the water. The hind legs are flattened and fringed with hairs, and are used as oars. This beetle is found in stagnant ponds, where it feeds on smaller animals, such as tadpoles, hidden in the refuse. In the aquarium it can be fed on small worms or tiny pieces of raw meat.

The same kind of food can be given to the larger water beetles. In the pond they eat sticklebacks, tadpoles, and snails, and so should be kept entirely by themselves in a dish containing a deep layer of sand. There are several common kinds, one, *Dytiscus* (meaning "fond of diving"), being over an inch in length, and dark reddish brown with a red border. It swims easily, the hairy hind legs serving as oars. Underneath the large wing covers lie crumpled wings, and the beetle often flies from one pond to another when food is scarce.



CADDIS WORMS. × $\frac{2}{5}$.
A. Case made of leaves of *Elodea*.
B. Case made of shell.



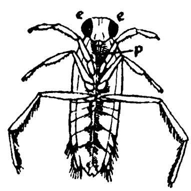


FIG. 41.

DORSAL SURFACE OF WATER SCORPION. × $1\frac{1}{5}$.

a, Air tube.
b, First pair of legs.
w, Wings.

VENTRAL SURFACE OF WATER BOATMAN. × 1.

e, Compound eye.
p, Proboscis.

The female lays her eggs in the stems of water plants. The egg-laying organ is at the hind end of the body, and by means of this a cut is made in a stem and one egg laid. In April, about three weeks after the eggs are laid, a tiny **larva** hatches out from each, and feeds greedily until it reaches its full length of two inches or more. It is pale brown in colour, with a long, jointed body and six legs. It swims by means of the hairy legs and tail, frequently floating at the surface of the water to breathe. To do this, it reaches the surface head downwards, and pushes its tail out of the water. In the tip of the tail are two openings called spiracles (L. *spiro*, I breathe), through which air enters and passes into the long air tubes, which extend the length of the body. The food of the larva consists of tadpoles, fishes, snails, worms, and smaller creatures, which are caught by the sharp, curved jaws. Each is hollow, and through it the larva sucks the blood of the victim. Soon after reaching its full size, the animal stops feeding and changes into a **pupa**, which is a resting stage in the life history of an insect, between the larval stage and the adult condition. To do this, it swims to the edge of the pond and buries itself in the soft mud very close to the surface. It loses its head parts and limbs, becoming short and broad and much paler in colour. This change takes place usually in the summer-time and lasts for about a fortnight. Meanwhile the adult beetle, or **imago**, is forming inside the pupa case, and eventually it breaks through and creeps out of the moist earth. At first it is quite pale in colour, but soon changes to its characteristic dark brown. You will understand now why you need a good layer of sand or earth in the aquarium where you will keep the beetles. In fact, the soil should be piled up round the edges of the dish to reach the surface of the water.

THE DRAGON-FLY.

The dragon-fly larva is a soft-bodied, dull-coloured creature, easily hidden in the mud at the bottom of a pond. It is about an inch long, and is found in stagnant water. As it is carnivorous, it must be kept entirely by itself. For a year or more the insect remains a larva, and moults, that is, sheds its skin, several times. Then the dragon-fly forms inside the skin, and the larva crawls up the stem of a water plant till it is above the surface of the water. The larval skin splits, and the beautiful fly emerges.

THE WATER SCORPION.

The water scorpion is easily recognised by its pincer-like fore legs and long breathing tube at the hind end of the body. Its food consists of small insects, which it seizes in its strong fore legs, but, unlike *Dytiscus*, it pushes the food directly into its mouth. It swims slowly about at the bottom of the pond, and when it comes to the surface to breathe, its long breathing tube is pushed out of the water and air enters. The eggs are laid singly in holes made in water plants, and develop similarly to those of *Dytiscus*.

Caddis-Worms.

Caddis-worms are found in most ponds. Search among the mud and leaves you get in your collections, and you will probably discover curious creatures, part of whose body is hidden inside a case, while the other part, consisting of a head and six legs, projects from it. The case may be made of leaves, shells, or fragments of either sand, gravel, or other available material. The larva inside is soft-bodied and very much like a caterpillar in appearance. It hatches from an egg laid by the caddis-fly, which is dark-coloured and has four wings. These "worms" should be kept in a large dish containing fresh water and plenty of water plants, on which they feed. They cannot live in stagnant water, and so it is advisable to keep water snails with them. The worm will creep slowly over the surface of the aquarium, dragging its heavy case with it, and breathing by means of long white threads coiled round its body inside the case. It does not come to the surface to breathe, but takes oxygen from the water passing over the breathing tubes. As it grows, it often adds pieces to the case, and these are woven together by a sticky substance which flows from the spinneret near the mouth. Around itself it also spins a silken case inside the hard one. At the hind end of its soft body are two horny hooks which help to keep it in the case, so that it is extremely difficult to remove without injury. Towards the end of May or the beginning of June the larva pupates. It closes the case at both ends with a silken covering, leaving a small hole in each, so that water can flow through. The pupa inside is enclosed within a silken case, and when it is ready to change into a caddis-fly, it leaves the hard case, crawls out of the water up the stem of a plant, and there the silken case splits and the caddis-fly comes out.

THE GNAT.

Gnat larvæ are not desirable creatures to keep in your aquarium, but you may get some in your collection, especially if it be made in stagnant water, and you may be interested in watching the development. Keep the larvæ in a jar of stagnant water, covered over with a piece of muslin. They feed upon decaying substances and small insects. The larva, about half an inch long, hangs upside down at the surface of the pond, so that the spiracles are above water. In this position it feeds, and, like other larvæ, from time to time it moults. After the third or fourth moult it changes into a pupa, the perfect insect, or imago, being already almost fully formed inside the case. The pupa floats head upwards, with the spiracles, now at the head end, above water. When the imago is ready to escape, the skin splits along the upper surface of the head and thorax, and the gnat stretches its wings and flies away. It is only the female that bites. She lays her eggs in masses about a quarter of an inch across at the surface of the water, where the little egg-raft floats till the larvæ emerge.

THE SILVER SPIDER.

The silver spider and other water spiders may be kept with water snails. Watch their movements as they swim through the water. Each builds a dome-shaped nest amongst the plants and mud at the bottom of the pond, and will probably do so in the aquarium. The spider rises to the surface of the water and collects air to fill the nest, which is open at the bottom. To do this, the hind end of the body is pushed out of the water, and when it is drawn in again you will see a bubble of air apparently grasped by the spider. It carries the air bubble to its nest, sets it free inside, and continues until the nest is filled. Contrary to what is the rule with most spiders, the male of the silver spider is larger than the female, and each builds a nest, where it lurks on the watch to catch any small creature which may venture near. The female lays nearly a hundred eggs, which are protected by a large egg-case; and when the eggs are hatched, each young spider is provided with an air bubble.

THE LEECH.

You may find on the surface of the glass some dark-brown or nearly black creatures, which move by alternately narrowing and broadening the body, or by drawing the hinder end close to the fore end and then stretching out again. These animals are leeches, and have soft, flattened, segmented bodies. On the ventral surface you will see two discs or suckers, one at the hind end and the other at the head end. In the middle of the latter is an opening, the mouth, which is furnished with three peculiar tooth-plates like saws. By means of these the leech pierces the skin of its prey and feeds on the blood.

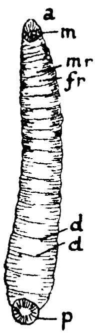


FIG. 42.—DIAGRAM OF VENTRAL SURFACE OF LEECH. × 2.

a, Anterior sucker.
m, Mouth.
p, Posterior sucker.
d, Division between true segments.
mr, Opening of male } reproductive organs.
fr, Opening of female } reproductive organs.

Its food consists of earthworms and insect larvæ, but there are larger species which attach themselves to horses and men and feed on their blood. The medicinal leech was used in former days by physicians to bleed their patients. Leeches are true worms, and, like earthworms, they lay their eggs in cocoons. These are deposited in the soft earth by the waterside, and from each egg emerges a tiny leech capable of living an independent life.

THE WATER FLEA.

The smaller creatures you will probably capture include the water flea, which can be seen as a small white speck darting about in the water. Keep water containing the fleas in a separate jar, and from time to time add some to the dishes containing dragon-fly larvæ, gnat larvæ, and silver spiders.

The larger water animals and plants will be dealt with in the next chapter.

ADDITIONAL PRACTICAL WORK

[Names and addresses of agents supplying certain biological specimens may be found in *School Nature Study*, the official organ of the School Nature Study Union. Secretary: Mr. H. E. Turner, 1 Grosvenor Park, Camberwell, London, S.E. 5.]

1. Take a caddis-worm and gently split open the case so that you can see the caddis. Place it in a shallow dish containing water and examine it carefully. In the dish place material for making another case; but give the worm different material from that already used. For instance, if its case were made of leaves, give it sand and gravel and no water plants. See that it has food. Watch carefully, and if it makes another case, note the way this is done and the time taken.
2. Keep one water snail by itself, and make notes and diagrams of its growth.
3. Keep several masses of snails' eggs for observation. Count the number of eggs in each and note the dates of laying and hatching.
4. Place about the same quantity of water plants in each of two dishes of water, and compare their growth when one is placed in a dark cupboard and the other in strong sunlight. See that the difference in light is the only difference in the treatment of the two sets of plants.

QUESTIONS AND EXERCISES

1. Name any animals which should be kept separately in aquaria, and give reasons.
2. Why is it that these animals are able to live together in the same pond?
3. Make a list of creatures which—
   (*a*) Breathe air by coming to the surface of the water.
   (*b*) Take in water and extract the oxygen from it.
4. Describe the life story of *Dytiscus*, and compare it with that of the dragon-fly.
5. By what means does the snail rise to the surface of the water and descend again?

   Compare these actions with those of the silver spider.

6. Explain why such creatures as the gnat larva, which is heavier than water, can float.

7. How are the wings of water beetles protected?

8. What are spiracles? Describe their position in different aquatic insects.

9. Describe the life history of the gnat.

10. Compare the positions of the spiracles in the larva and the pupa of the gnat. Give reasons for the change in position.

11. Suggest a way of getting rid of gnats by killing the larvæ, giving your reasons. Say whether your method could be used on large stretches of water.

12. What is meant by *carnivorous*? Describe any carnivorous inhabitants of the aquarium.

CHAPTER VII

HOW TO STUDY THE LARGER AQUATIC ANIMALS AND PLANTS

The Stickleback

YOU will probably find minnows and sticklebacks in your collections, and these can be kept with water snails and plants in an ordinary aquarium.

MOVEMENT AND EXTERNAL CHARACTERS.

Study the movements of the fish in the pond. It swims easily, head foremost, with a graceful side-to-side motion of the body. When it is moving slowly, you will be able to see that the tail end of the body is bent first to one side, then to the other, the head end at the same time bending in the opposite direction. The rapid straightening of both head and tail, aided by the powerful posterior muscles, causes the fish to move forward. The alternate side-to-side movements keep it in a straight course.

The general shape of the stickleback is like that of a cigar. This shape is the best for movement wholly in one medium, such as water or air, because the greatest resistance is offered by the widest part of the body, so that the narrow posterior end offers hardly any at all. Man has copied this streamline shape in building the submarine, the torpedo, and the airship. The body of the fish is flattened from side to side, enabling it to cut through the water, since there is less surface for the downward pressure to act upon. The "cutwater" movement is increased by the form of the dorsal and ventral fins. You will notice that these and the tail fin are arranged singly, while the others are in pairs. The position of the fins varies in different fishes, and the dorsal fin is often divided into several parts.

The dorsal fin of the stickleback is cut into one fin and several spines or "stickles". There is also a caudal or tail fin, and an anal fin situated posterior to the openings on the ventral surface. Anterior to these openings are two pairs, the pelvic and the pectoral fins. The dorsal and anal fins act as

THREE-SPINED STICKLEBACK. × 2.

a. Anal fin.
d. Dorsal fin.
c. Caudal fin.
p. Pectoral fin.
p.v. Pelvic fin.
o. Operculum.

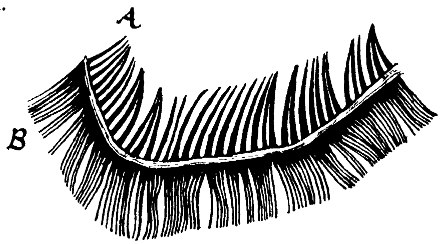


FIG. 43.

GILL OF HERRING. × 1.

A. Gill rakers. B. Gill filaments.

cutwaters like the keel of a boat, while the caudal one acts similarly to a rudder, helping to steer the fish. The paired fins are used as balancers, and may be compared to the limbs of higher creatures. The fish helps to defend itself by means of its spines.

On the ventral surface there is usually a small spine anterior to the anal fin, and one or more larger spines attached to the pelvic fins. The common fresh-water stickleback has three spines as part of the dorsal fin, but in other species we find a larger number in this position.

The fins are folds of skin supported by rays, and may be compared to a fan, the ribs of which represent the bony rays. They can be folded back against the body in much the same way as a fan can be folded.

In many fishes there is a torpedo-shaped sac, the swim bladder, which may be filled with a mixture of gases consisting mostly of oxygen and nitrogen, and may be deflated. When the fish is about to rise in the water, the cells lining the bladder secrete the gases, inflating the sac and making the fish more buoyant. When the gases are reabsorbed by the cells, the bladder becomes deflated and the fish sinks. So by regulating the volume of gases in the swim bladder the fish can swim at different levels.

The skin is made up of two layers, a thin epidermis covering a thicker dermis, which usually bears scales. Each scale overlaps the one behind, and this arrangement permits of the side-to-side movement of the body in swimming. The overlapping edge of the scale is ragged in the stickleback, but in other fish it may be smooth. When we look at scales under the microscope, we find that each one shows circular markings, for the scale grows by the addition of a ring of substance round its outer edge. The spaces between the rings are alternately wide and narrow, the reason for this being that the growth in summer is greater than in winter. Thus, by counting the rings on a scale, we can find the age of the fish. The scale is made of a bony substance, and fits into a little bony socket in the dermis. The body of the stickleback is not completely covered with this kind of scale. There are also large, bony plates called scutes (L. *scutum*, shield). Many species of stickleback are entirely covered with scutes, arranged in lateral and dorsal rows, while others are scaleless except for large scutes at the anterior end. The thin, transparent epidermis peels easily and secretes a slimy fluid. The dermis is thicker, and the colour of the fish depends on the colour bodies found in it. If you examine the stickleback under a strong lens, you will see these as tiny, dark, irregular bodies. There is also in the dermis a colouring matter, which gives the fish its silvery appearance. Notice how the colour of the ventral surface differs from that of the dorsal. This distribution of colour is similar to that found in many animals, and has been already explained in Chapter IV.

Some fish—for example, the haddock—gleam brightly in the dark, and this same phenomenon, phosphorescence, may be observed in shoals of fish in the surface water of the sea. It is commonly said that this is due to the large amount of the element phosphorus contained in the fish, and as phosphorus is good for the brain, therefore fish is good food for the brain. There is, however, no foundation for this belief, phosphorescence being due in some cases to the presence of bacteria—microscopic creatures, millions of which may cover the skin of one fish—and, in others, to the secretion of a light-producing substance. Some fish living in deep water possess special phosphorescent "cups" sunk into the skin of various parts of the body, but mostly near the eyes. Certain cells in these cups secrete a luminous substance. A part of the cup acts as a reflector, and a black lining acts like the walls of a camera. These luminous cells cease to produce light when the fish dies.

On either side of the body of the fish, but not easily seen, is the lateral line, marking the position of a groove or tube beneath the skin. Each line is supplied with nerves, which are diffusely sensitive to vibration, light, pressure, and other changes in the medium surrounding the fish. In the stickleback, the lateral lines stretch half-way along the body, beginning at the tail, but in other fishes they usually extend the entire length of the body.

Observe carefully eyes and mouth, and find out whether the eyes are provided with lids. The stickleback's mouth is at the anterior end of the body, but in other fish the mouth may be on the ventral surface. Lie down flat on your face, and you will realise that your mouth is on the ventral surface too. The position of the mouth may be associated with the shape of the tail. Where the lobes of the caudal fin are equal, as in the stickleback and herring, the stroke of the tail tends to drive the body straight forward, so that the fish catches its food by straight-forward movements, and the mouth is terminal. The movement of the tail of the shark and other fishes, where the dorsal lobe of the caudal fin is much larger than the ventral one, tends to force the head end downwards so that the body moves through the water obliquely, and the fish is either a ground or a surface feeder with a ventral mouth. The shark, for example, swims on its back when feeding, catching its food from the surface of the water by means of the upwardly directed body movements.

In higher animals the ear has an external opening and an internal one communicating with the mouth. The ears of the fish, however, are merely round patches on either side of the head, and are difficult to find externally. The nostrils are dorsal to the mouth, and you will see them as pits or depressions in the skin. They have no connection with the throat, and their use is probably to smell and test the freshness of the water. The mouth contains teeth, which have no roots. They grow from the skin, and when worn away or lost are easily replaced. Some fish, like the haddock, have teeth on the roof of the mouth. The tongue, too, may be covered with teeth, and is usually immovable.

On the ventral surface of the body are two openings just anterior to the anal fin. The one nearer the fin is the exit for products of the bladder and reproductive organs. The other is the anus, through which all solid waste matter is excreted.

Breathing.

The slit on either side of the head is the opening of the gill chamber. The four gill arches can be seen when the flap, or operculum (L. *operio*, I close), covering the chamber is lifted. They lie one over the other, and between each pair is a gill cleft opening into the pharynx. Each arch bears on its outer convex side tiny bright red tubes, the gill filaments, while on the inner concave side are coarser projections, the gill rakers. In order to obtain sufficient oxygen, as large an area of the gill as possible is exposed to the water, and the gill is therefore split up into numerous tiny filaments.

When the fish breathes, water enters the mouth, which then closes, forcing the water into the pharynx. The walls of the pharynx immediately contract, forcing the water through the gill clefts, where the dissolved oxygen is extracted by the blood in the gill filaments, and the water passes on through the gill chamber and escapes through the opening.

FEEDING.

The stickleback feeds on small worms and other soft-bodied pond animals. The water containing the food enters the mouth and passes on into the pharynx. The gill rakers prevent the food from being lost again through the openings, and it passes on through the gullet into the stomach. Here digestion begins, as there are no salivary glands in the mouth. At the junction of the stomach and intestine is a collection of long filaments, which probably secrete a digestive fluid into the intestine. The long, fairly straight intestine receives the food in a fluid condition, and when absorption has taken place through its wall the waste matter is excreted at the anus. In most fishes the intestine is so short that we often find the lining folded in some way to increase its surface so that more absorption can take place. In the shark and dogfish the fold develops spirally and resembles a spiral staircase.

Some fishes feed on plants, many of which are microscopic, while others attack and eat smaller fish. Feed the sticklebacks in your aquarium on blood-worms or "gentles", which can be obtained from a live-stock dealer. Cut a worm into small pieces, and allow two worms per stickleback per day. If these be eaten at once, try giving a larger portion, but if any be left in the water till the following day, remove them and decrease the allowance. Always remove stale food from the water; you can do this with a long pair of forceps.

REPRODUCTION.

In the pond the stickleback lays her eggs in a nest. You may be able to watch nest-building in the aquarium, provided you see that the materials needed, water weeds and twigs, are present. The male builds the nest, weaving the material firmly together with mud and a sticky fluid secreted by the kidney. In shape the nest is barrel-shaped and at first closed at one end; it is moored to water reeds. The female lays in it about half a dozen eggs. She often breaks though the closed end and swims away, leaving the nest open at both ends. Usually several females lay eggs in the same nest, and each leaves the male to tend them; he adds spermatozoa to the eggs as soon as they are laid. In spring, when nest-building is proceeding, the male can easily be distinguished from the female by his red breast and pugnacious habits. He will fight any creature who dares venture near the nest, and uses his spines to some advantage. At the end of two or three weeks the eggs hatch, and the young escape from the nest.

The Trout

The majority of fishes can live only either in fresh water or in sea water. The fresh-water stickleback, however, will survive if placed in sea water, while such fishes as the trout, salmon, and eel pass their life partly in fresh and partly in salt water. The trout begins life in fresh water, hatching from an egg laid in the upper reaches of a river. The parent deposits her eggs in furrows, which she makes in the sandy or gravelly soil of the river bed, and as the eggs are laid the male sheds over them spermatozoa. The eggs are left to hatch, the time taken to hatch depending on the weather. In some cases they have been known to hatch in six weeks; in other cases they may take five months. As spawning takes place during the winter months—mostly in November and December—the young emerge in spring and early summer. They are curious little creatures, for when they escape from the egg they have attached to them part of the egg yolk, on which they proceed to feed. During this period, lasting from four to eight weeks, they lie quietly among the stones in the river bed, but when the yolk supply is exhausted they swim about in search of food, which consists of tiny water plants and animals. The fish are about one inch long at this stage, and grow very slowly. Their colour, which at first is orange with red and black spots, changes when they are two or three years old, becoming more silvery, with a line of black spots extending along the body below the lateral line, and when this change takes place they swim down the river to the sea, where they live not far from the river mouth. In the sea they grow more quickly, feeding on sticklebacks and other small fish and small crustaceans. Along the north-east coast of England they are said to feed mostly on sand eels. They migrate to the sea in spring and early summer, and there they spend one or two years, returning to the river in the autumn. It is an interesting sight to watch them swimming upstream, as, with their powerful strokes, they sometimes leap over the rocks and boulders in the river bed. When they reach the higher river-levels, spawning takes place, and then the mature trout may return to the sea or remain in the river. The summer and winter scale growth is very well marked in the trout, so that it is quite easy to determine the age of the fish at any stage in the life history.

The Crayfish

An aquatic animal found in rivers and streams, especially in limestone or chalk districts, is the crayfish, with a dull greenish-coloured body about three inches in length. The sea crayfish, or Norway lobster, is larger, but similar in habit and structure. The body is segmented, five segments making up the head, eight the thorax, and six the abdomen. At the posterior end of the abdomen is the tail fan, used as a paddle in locomotion. The skin secretes a thick, hard covering or exoskeleton containing calcium carbonate, and forming an external skeleton to the inner surface of which the muscles are attached. At the junctions of the segments the skin is much softer and allows the body to bend. Since the hard covering cannot grow, it is frequently split and shed. While moulting, the crayfish hides until the new exoskeleton is formed. The young crayfish moults frequently, but the male adult sheds his covering once a year and the female sheds hers twice as often. The segments are not clearly visible at the anterior end of the body, since the head and thorax are covered by a shield, the carapace. The segments, however, are distinct internally.

Notice the numerous appendages, one pair being found on each of the nineteen segments. The appendages are many-jointed and differ in structure according to their use. The two most anterior pairs, the short antennules and the longer antennæ, act as sense organs. The next six pairs are short and used as jaws. They arise close to the mouth and help to push into it the food, which is seized by the large pincers with their strong claws. Behind these "jaws" are four pairs of legs used for walking.

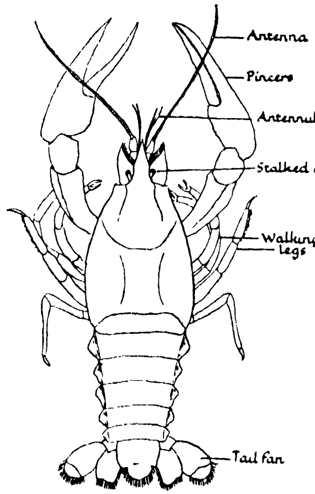


FIG. 44.—CRAYFISH. × ½.

The appendages on the abdomen are much smaller and flatter than the others, the two anterior pairs being of use in reproduction, the others, the swimmerets, acting as paddles. The most posterior pair are very broad and flattened, and with the last segment, the telson, form the tail fan.

The eyes are compound, that is, each consists of many simple eyes, and are stalked, so that they project well from the head. Their black colour is due to the amount of pigment they contain and which is visible through the colourless, transparent surface of the eye. The stalks can be moved by means of muscles. The mouth is on the ventral surface of the head and contains no teeth. There are neither ears nor nose, but at the base of each antennule and on its dorsal surface is a slit-like sac fringed with stiff hairs. It contains fluid in which are embedded particles of sand placed there by the pincers of the crayfish. In the thin wall of the sac are the endings of nerve fibres, and according to the position of the animal different patches of nerve fibres feel the presence of the sand grains. This organ thus serves as a balancing organ, while on the ventral surface of each antennule are special bristles acting as organs of smell.

At the base of each antenna, on the ventral surface, is a small swelling in which is the opening of a gland, the "green gland" or kidney, which lies just beneath. The colour of the gland is due to a greenish-coloured waste product excreted by the kidney.

The rapid backward movements of the crayfish are the result of the alternate straightening and bending of the body by means of powerful abdominal muscles. At the same time the tail fan is spread and acts as a balancing organ. In moving forward, the animal uses its walking legs and swimmerets, six of the eight walking legs usually touching the ground together. The two off the ground are on different segments and on opposite sides.

The food of the crayfish is varied, including worms and other creatures which it can seize in its strong pincers. The food is pushed into the mouth by the jaws, and passes into the first part of the digestive tube, the fore gut. This part is lined with epidermis, and is separated into a short, wide gullet and a stomach, in which are stout plates, some bearing teeth. The food is crushed in the stomach or gastric mill, and passes through the mid gut to the hind gut. This also is lined with epidermis, and the anus is situated on the ventral surface of the telson. During moulting, not only is the exoskeleton shed, but also the lining of the fore and hind gut.

The crayfish breathes by means of gills protected within gill chambers formed by the carapace. These chambers are found at the base of every appendage of the thorax. The gills are thin-walled and much branched, so that as large an area as possible is exposed to the water surrounding them. The fifth pair of appendages forces a current of water through the gill chambers. Oxygen is extracted by the blood in the numerous capillaries just within the thin gill wall.

An opening for the passage of egg-cells or spermatozoa is found at the base of each of the eleventh pair of appendages in the female and the thirteenth pair in the male. The eggs are laid usually in November, and are hatched in the following summer. They do not pass through any larval stages, but resemble their parents. For some time after hatching they may be seen clinging to the posterior appendages of their mother or to the empty egg-shells.

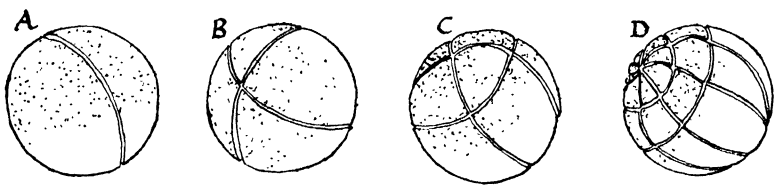
Like the earth-worm, the crayfish has the power of regeneration of lost parts. Should a limb be lost, a new one grows in its place beneath the cuticle, but remains very small until the cuticle is shed. At each moult the appendage increases until it reaches the normal size.

The Frog

DEVELOPMENT.

In late February and March you will find in the pond masses of jelly-like substance speckled with black spots. Collect a handful of this frog's spawn and keep it in a dish of water with water weeds. It is always found in shallow water, and with it you may find toad's spawn, which is similar in appearance but is arranged in long strings like necklaces wound round water plants. Newts' eggs are more difficult to find, for the mother places each egg in the leaf of a water plant and sticks together the leaf edges for protection. In all cases the eggs are left to hatch, the necessary warmth being supplied mostly by the sun. It is therefore essential that they should be as near the surface of the water as possible. The frog lays several hundreds of eggs at a time, each being a small, black spherical object nearly two millimetres in diameter. As the eggs leave the body of the mother each becomes surrounded by a gelatinous envelope, which swells on contact with the water. These gelatinous coverings help to make the egg mass buoyant by the inclusion of air bubbles between them and ensure room for the development of the eggs by spacing them well apart. The slimy material is also probably distasteful, and so prevents the eggs from being eaten by other animals.

Examine the eggs through the gelatinous coat, and you will find that each is bi-coloured, the black surface floating uppermost with the white surface below. Unfertilised eggs can be distinguished by their floating with half the white



EGG OF FROG (MUCH MAGNIFIED) SHOWING CHANGES DURING EARLY DEVELOPMENT.

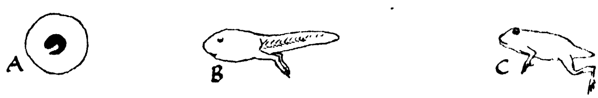


FIG. 45.—DEVELOPMENT OF FROG.

A. Young tadpole just before hatching.
B. Tadpole with hind legs.
C. Tadpole ready to leave the water.
} × ½.

and half the black surface showing. If you could look through a powerful lens at a developing egg, you would notice changes in the appearance of the surface. First appears a vertical furrow, similar in position to a large circle or meridian round the globe, then a second furrow, corresponding in position to another meridian, at right angles to the other. A third furrow appears in an equatorial position, and thus the egg surface is divided into eight parts, the upper four being somewhat smaller than the lower. Division continues until the egg is cut up into layers of cells, and as cell-division is more frequent in the upper black area, the cells here are much smaller than those in the white area. Imagine a golf ball with larger surface divisions covering one half, and you will have an idea of the appearance of the egg at this stage. The black area forms the tadpole; the white area represents the food store or yolk, and is used up in development.

Watch the egg carefully each day, and note the changes in shape. It gradually grows until it becomes longer than the inner diameter of the gelatinous envelope. This causes the developing tadpole to become coiled and flattened, until, in about three weeks after the egg was laid, a curious black creature breaks through the envelope and escapes into the water. The tiny tadpole attaches itself to a water plant by means of a sticky patch, the cement gland, on the anterior ventral surface. On each side of the body project tiny filaments, the gills, by means of which it breathes. It has no mouth, but feeds on the remainder of the yolk which is contained in the swollen ventral part of the body. The gill filaments grow longer and increase in number until there are three pairs on each side. The triangular mouth develops anterior to the cement gland, and the tadpole breaks free from the weeds and nibbles water plants by means of the tiny pointed teeth. It swims through the water, using its trunk and tail in the same way as a fish. Soon the eyes appear, breaking through the skin which has covered them. The gills gradually shrivel, and in their place you will find a respiratory tube which opens into a chamber containing the gills. The right-hand tube shrivels and the gill chamber is covered with a thin skin or operculum, but the left-hand tube persists for a long time. The tadpole now breathes in the same way as a fish, by gills on both sides, but the water has only one outlet, that on the left-hand side.

After about seven weeks, the skin changes colour, becoming pale and speckled, and the tail lengthens, until the creature is between one and two inches long. The body narrows where the tail joins the trunk, and here two bulges appear, and gradually grow larger, assuming the shape of legs. These are the hind legs. The fore legs are growing at the same time, but are inside the gill chambers, and appear when the hind legs are fully formed. The left fore leg pushes through the respiratory tube, and usually appears before the right leg, which has to break through the operculum. Meanwhile changes go on inside the tadpole. At first you can see, showing through the thin skin, the loosely coiled intestine, and this becomes more tightly coiled and covered with a layer of muscle. Lungs develop, and the gills gradually disappear, until all that is left to mark their position externally is the respiratory tube on the left side of the body and through which water can still escape. The tadpole rapidly loses its fish-like appearance and habits; it comes to the surface of the water to breathe and its tail gradually shortens, for its owner is feeding on it! You will not actually see the tail being eaten, as it is gradually dissolved from within, and while this goes on the tadpole does not eat other food. Then the tiny frog, with its stumpy tail, leaves the water and lives near the pond, feeding on flies and other insects. The very young tadpoles in the aquarium will feed on water plants, but when about six weeks old they become carnivorous, and occasionally should be given tiny pieces of raw meat. These may be tied on to a string and lowered into the water, so that they can be removed easily when stale. Unless the tadpoles have a good supply of meat food, either in the form of tiny water animals or raw meat, at this stage they will attack and eat other tadpoles.

External Characters.

Look at a frog and notice the shape of its body. There is neither neck nor tail. Compare the length of hind and fore limb, and count the number of digits (toes or fingers) on each limb. The male is distinguished, especially in the breeding season, by the thickening of the "thumb", and this enables him to grasp the female firmly when pairing. You may often see pairs of frogs in springtime. When the eggs are ready to be laid, the male climbs on to the back of the female, and as the eggs escape he covers them with a mass of spermatozoa. As you may read in Chapter III, a spermatozoon fuses with the egg-cell and fertilises it.

Make a list of the adjectives which describe the nature of the skin. Among your adjectives you may have "loose-

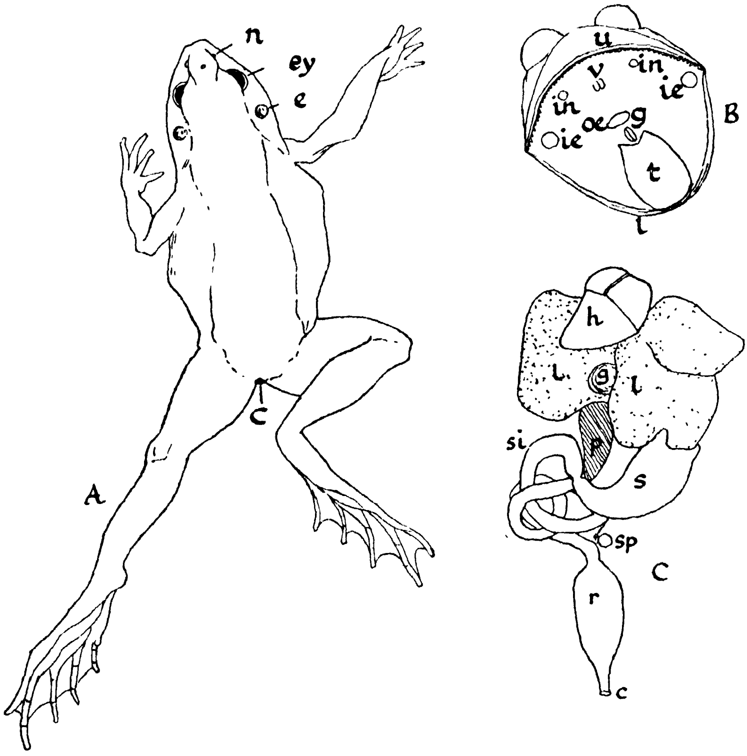


FIG. 46.—FROG.

A. DORSAL VIEW—*ey*, Eye; *n*, Nostril (external); *e*, Ear; *c*, Cloacal aperture. × ½

B. MOUTH CAVITY—*g*, Glottis; *œ*, Gullet; *t*, Tongue; *ie*, Internal opening of ear, *in*, Internal nostrils; *v*, Vomerine teeth patches; *u*, Upper jaw; *l*, Lower jaw. × 1

C. DIGESTIVE SYSTEM AND HEART—*h*, Heart; *l*, Liver; *g*, Gall-bladder; *p*, Pancreas; *s*, Stomach; *sp*, Spleen; *si*, Small intestine; *r*, Rectum; *c*, Cloacal aperture. × 1

fitting", "slimy", and "speckled". The bagginess of the skin is due to the fact that between it and the layer of muscles beneath is a space filled with lymph, a colourless, watery fluid containing certain dissolved food materials. The skin itself is made up of two layers. The outer thin one, the epidermis, is often shed and eaten by the frog, the whole skin being changed in this way about four times in a year. Beneath the epidermis is a thicker layer, the dermis, containing numerous tiny blood vessels and small glands. Each gland has a neck or duct, which is a tube with an opening or pore on the surface of the skin. One kind of gland secretes a watery, antiseptic fluid which helps to keep the skin free from "germs" and is continually rising to the surface. In the toad this fluid is slightly poisonous. The other kind of gland secretes a slimy liquid which keeps the skin moist. As long as the skin is kept moist, the blood vessels in the dermis have the power of extracting oxygen from the air; thus the frog can breathe through its skin as well as by means of its lungs. During the winter, when it lies buried in damp mud for a month or two, the frog may breathe entirely by its skin. You have no doubt noticed that frogs always live in damp places, or not very far from water, so that the skin never becomes quite dry. The colour of the skin is due to colour bodies in the dermis, and these have the power of becoming larger or smaller. When they are expanded the colouring matter they contain is spread out more, making the skin look darker than when they are contracted. Compare the colour of the dorsal and ventral surfaces.

Look at the web between the toes of a living frog. By holding the frog carefully, you can examine the web under a good lens, or a low magnification of a microscope. The skin is so thin that through it can be seen arteries, veins, and capillaries. The arteries may be distinguished by the fact that blood in them flows from larger to smaller vessels, whereas in veins it flows from the smaller vessels to the larger ones. With the help of a more powerful lens, it is possible to see the white corpuscles collecting along the walls of the vessels and even passing through them, and the red corpuscles squeezing through the narrow capillaries. Notice also the colour bodies in the skin.

Are there any scales, nails, or claws?

There are various openings in the body of the frog. At the posterior end, between the hind legs, is the cloacal opening for the products of alimentary canal, bladder, and reproductive organs. Notice the shape of the head. The eyes bulge and are provided with three eyelids. The upper and lower ones are but slightly movable, while the third one, the nictitating membrane (L. *nicto*, I wink), is attached to the lower and is flicked across the eye to remove dust. The hollow or socket in which the eye fits is very soft, and as there is no bone between it and the mouth the socket can be pulled downwards, so that the back of the eye bulges into the roof of the mouth. Behind the eyes are a pair of dark, circular patches, covering the ear drums. Find whether the ears have flaps. The nostrils are two small openings anterior to the eyes. Note how the position of eyes, ears, nostrils, and mouth enables the frog to keep them above water when swimming.

Food and Digestion.

The mouth is large, and only the upper jaw contains teeth, which are fixed like those of the fish. There are two groups of teeth, the vomerines, actually on the roof of the mouth, and these assist the frog not in chewing but in gripping its food. Near them, in the roof of the mouth, are two small openings, the internal nostrils. The mouth has a soft lining of cells bearing cilia and secreting fluid. The movement of the cilia keeps the fluid in constant motion in the mouth, and so ensures its being kept clean and moist. The club-shaped tongue is fixed to the front of the lower jaw, and is flicked out and in very rapidly when the frog catches a fly. The forked tip of the tongue is therefore at the back of the mouth, and its sticky surface prevents the escape of the insect. When capturing an earth-worm or other large creature, the frog uses its teeth to get a firm hold on the slippery body, which it swallows whole and in gulps, the worm disappearing inch by inch. At each gulp the eyeballs are pulled inwards, forcing the sockets into the roof of the mouth and so helping the palate muscles to get a firmer grip.

Where does the worm go when it has been swallowed, and what happens to it? In the first chapter you discovered that animals build themselves up, that is, they grow, by taking in different substances as food. This food eventually forms the body of the animal, but how does a worm become frog? It is changed, by digestion, from solid form to liquid, and this gradually passes into the blood and is carried by the blood vessels to all parts of the body. The frog has no salivary glands, so the food passes directly, as it does in the stickleback, through the gullet, and thence into the stomach. The shape of the stomach is similar to that of the cat, and the food is acted upon by the gastric juice and passes, by the opening of a circular muscle, through the narrow end into the small intestine. As in the cat, at the beginning of the small intestine bile and pancreatic juice enter, and absorption of the digested fluid food material takes place through the walls. The undissolved matter passes into the large intestine, where any remaining food solution is absorbed and waste is excreted through the cloaca.

The liver is a reddish-brown organ lying posterior and slightly dorsal to the heart, and spreading out on either side of it. It has two lobes, the larger left lobe being subdivided. The greenish-coloured gall bladder lies between the lobes, and its duct passes through the pancreas, which is seen as a long, pinkish-red, irregular-shaped organ lying between the stomach and the adjacent part of the small intestine. The pancreatic ducts join the bile duct as it traverses the pancreas. The spleen, a small, red, spherical organ, lies near the beginning of the large intestine, and its work is similar to that of the cat's spleen.

Circulation.

How is the food able to reach every part of the body? It is collected from the intestine by capillaries, and flows on into larger veins, through the liver, and thence into the posterior vena cava, which carries it to the heart. The heart of the tadpole, like that of a fish, is divided into one auricle and one ventricle only, and always contains impure blood on its way to the gills to be purified. During development

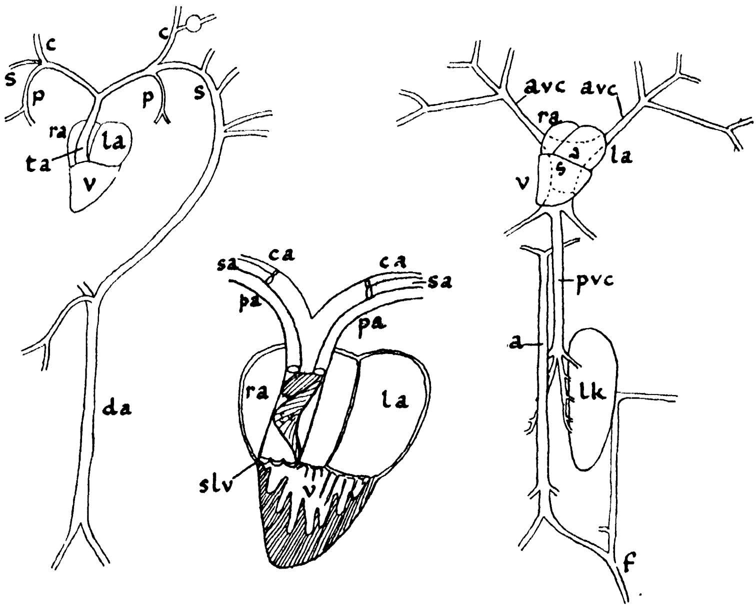


FIG. 47.

ARTERIAL SYSTEM OF FROG. × 1.

ta, Truncus arteriosus.
p, Pulmonary artery.
s, Systemic artery.
c, Carotid artery.
da, Dorsal aorta.

DIAGRAM OF FROG'S HEART, × 2½. SHOWING—

ra, Right auricle.
la, Left auricle.
v, Ventricle with thick walls.
ca, Conus arteriosus.
sv, Spiral valve.
slv, Semi-lunar valves.
pa, Pulmonary artery.
sa, Systemic artery.
ca, Carotid artery.

VENOUS SYSTEM OF FROG. × 1.

ra, Right auricle.
la, Left auricle.
v, Ventricle.
pvc, Posterior vena cava.
sv, Sinus venosus (outlined with dotted line).
a, Abdominal vein.
f, Vein carrying blood from legs.
lk, Left kidney.
avc, Anterior vena cava.

the heart changes, the auricle becoming divided into two, so that impure blood can enter one auricle and pure blood the other at the same time. The ventricle, however, remains single, so that the heart is three-chambered and not fourchambered, as in the cat. Therefore, when the thin-walled auricles contract, the impure blood from the right, and the pure blood from the left, auricle is forced into the ventricle. The backward flow of the blood is prevented by valves, membranous flaps attached to the wall of the ventricle by fine cords, so that when the ventricle becomes full the flaps are pushed up against the openings by the pressure of the blood, in much the same way as a parachute is kept open by the upward pressure of air. The ventricle has not only extremely muscular walls, but there are muscular projections into the cavity, making it of a spongy nature, so that the pure and impure blood mix very slowly. As the ventricle contracts immediately after the auricles, the blood is expelled from it before much mixing has been able to take place. This contraction forces the blood through the only exit, that of the muscular-walled truncus arteriosus, guarded by three semi-lunar valves to prevent the blood from flowing back again. The truncus arteriosus opens from the right side of the ventricle, so that the impure blood enters first, and is followed by mixed and then by pure blood. The blood flows along into the two branches of the truncus arteriosus, and each of these divides into three. The impure blood is forced into the first branches, the pulmonary arteries, which then become closed by a valve. The mixed, and part of the pure, blood flows through the next openings into the systemic arteries. When these are full, the rest of the pure blood is forced through much smaller openings into the carotid arteries. In this way the impure blood flows through the pulmonary arteries to the lungs, where it receives oxygen, and returns to the heart by the pulmonary veins opening into the left auricle. Imperfectly pure blood is sent to all parts of the body, except the brain and part of the head, by branches of the systemic arteries, is collected again by veins, and eventually reaches the vena cava, which opens into a thin-walled sac, the sinus venosus, on the dorsal surface of the heart. This sac pumps it into the right auricle. The brain, however, must be supplied with perfectly pure blood in order to be able to function properly, and receives it from the carotid arteries. So we find that—

Impure blood goes to the lungs via the pulmonary arteries;

Impure and pure blood goes to the body via the systemic arteries;

Pure blood goes to the head via the carotid arteries.

The red blood corpuscles give up their oxygen into the cells of the body tissues, with the resulting production of energy in the form of heat. As some of the blood is impure, it carries round less oxygen than it does in the cat, with the result that less heat is produced. The frog is therefore a cold-blooded animal.

BREATHING.

When the frog breathes, the floor of the mouth is lowered by the muscular action of the throat, at the back of which is a slit which can be closed or widened by muscular action. At the same time the mouth and glottis are closed, so air can enter only through the nostrils. When the mouth is full, the nostrils close, the floor of the mouth is raised, and the air is forced through the only remaining opening, the glottis, into the larynx. Owing to the absence of neck, the windpipe is extremely short and consists only of the larynx. This branches into two very short bronchi, which enter the lungs and subdivide many times until they end in capillaries. The

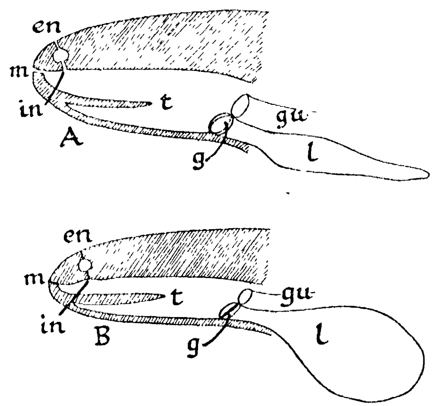


FIG. 48.—DIAGRAM OF HEAD OF FROG DURING BREATHING.

A. Mouth, nostrils, and glottis open; lungs empty.
B. Mouth, nostrils, and glottis closed; lungs filled.

m, Mouth; *en*, External nostril; *in*, Internal nostril; *g*, Glottis; *gu*, Gullet; *l*, Lung; *t*, Tongue.

two thin-walled, elastic lungs lie one on either side of the heart and are often partly covered by the liver. To increase the surface, the internal walls are thrown into folds, which project into and partly fill the lung cavity, thus causing it to be of a spongy nature. The exchange of gases in the lungs takes much longer than in those of the cat, so the frog breathes very slowly. Expiration of air from the lungs is caused by the movement of the throat and abdominal muscles, which exert a pressure on the lungs, causing them to collapse. Across the larynx are stretched the two vocal cords; these vibrate when air is forced between them, producing the sound described as the croaking of the frog. In some frogs the male has, in addition, two vocal or resonating sacs opening into the mouth cavity, one on each side at the angle of the jaw, and these cause the croaking of the male to be much more powerful than that of the female. In springtime, in the breeding season, when the frogs congregate, their croaking can be heard quite plainly, the powerful notes of the male being louder and clearer than the more feeble responses of the female.

REPRODUCTION.

The sexes in the frog are separate, the male having a narrower and usually a smaller body than the female. The testes, which produce the spermatozoa, are two ovoid, pale yellow bodies, about half an inch long, situated in the dorsal body wall of the male, one on either side. Each bears a bright yellow, lobed fat-body, and is connected with a kidney. The spermatozoa pass from the testes through the kidney by special ducts, and thence by the kidney ducts, the ureters, into the cloaca, whence they escape to the outside. Just before opening into the dorsal wall of the cloaca, each ureter bears a small pouch in which spermatozoa may be stored. The eggs are produced in two large ovaries, which in the breeding season almost fill the lower body cavity of the female and are attached to the dorsal body wall. Each contains hundreds of black and white spheres—the eggs. These escape to the exterior through thick-walled, wide, convoluted tubes, the oviducts, opening into the dorsal wall of the cloaca close

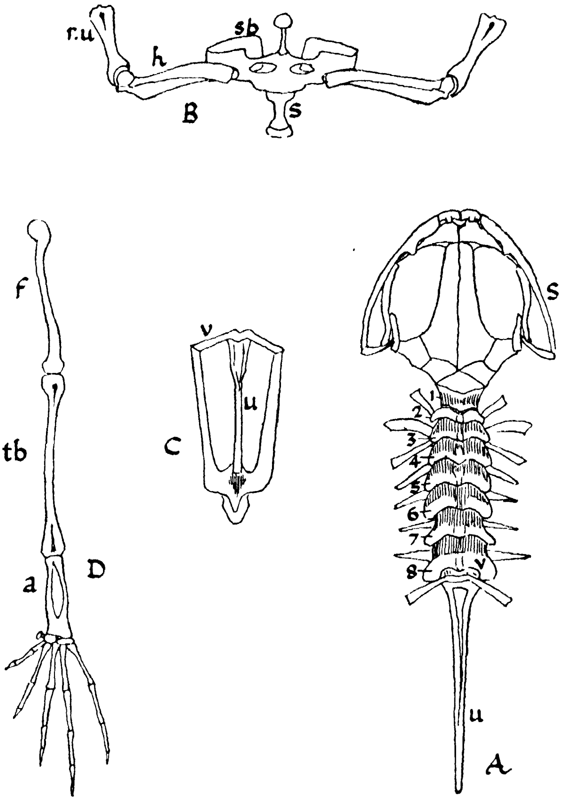


FIG. 49.—SKELETON OF FROG. $\times \frac{5}{8}$.

A. DORSAL VIEW OF SKULL AND VERTEBRAL COLUMN—*s*, Skull; *v*, Vertebra, *u*, Urostyle.
B. VENTRAL VIEW OF PECTORAL GIRDLE—*s*, Sternum; *sb*, Shoulder-blade; *h*, Humerus; *r.u*, Radio-ulna.
C. VENTRAL VIEW OF PECTORAL GIRDLE—*u*, Urostyle; *v*, Ninth vertebra attached.
D. LEFT HIND LIMB—*f*, Femur; *tb*, Tibio-fibula; *a*, Ankle.

to the openings of the ureters, which are separate tubes in the female and have no connection with the reproductive organs.

The kidneys are two flat, ovoid, red bodies attached to the dorsal body wall, one on each side of the backbone. They do the same kind of work as those of the cat, and the waste liquid is excreted through the two paired ureters. Opposite to the two openings of these is that of the bi-lobed, thin-walled bladder, which lies ventral to the cloaca, and thus has no direct connection with the ureters.

In the autumn, the fat-bodies, which are found in both male and female, are very large, but during the winter, when the frog lies buried in the mud, the internal store of fat is gradually used up for food, and the fat-bodies dwindle. They increase in size again during the summer.

MOVEMENT.

Watch the movements of a frog, and note the efficient use of the hind legs. Each has three parts, which act as levers, and their sudden stretching propels the frog off the ground for quite a long distance. The frog therefore moves by a series of jumps or springs. When at rest, the levers are folded one against the other in the form of a "Z". In swimming, the alternate stretching and bending of the hind limbs forces the frog forward, the fore limbs at the same time acting as paddles and helping to keep the head above water.

What enables the frog to use its hind legs so efficiently? It is partly due to the powerful muscles clothing the limbs. The arrangement of these is similar to that in the cat, and their alternate contraction and expansion brings about the body movements. Thin sheets or layers of muscles lie just beneath the skin of the trunk and head. Without muscles, the skeleton would be immovable. The frog's skeleton is not made entirely of true bone, parts being composed of cartilage. The skull is made of both. The spine consists of nine bony vertebræ, the last of which is joined to a long thin rod at the posterior end. The limb girdles are attached to the vertebral column and are composed of both bone and cartilage. The fore limbs are attached to the pectoral girdle and the legs to the pelvic girdle. Each limb consists of bones arranged similarly to the limb bones of the cat, but the radius and ulna are fused together in the fore limb and the tibia and fibula in the hind limb. In the fore limb there are six small bones in the wrist, arranged in two rows of three each, four complete digits, and a tiny bone marking the position of the thumb. The ankle is composed of two long bones and two very small ones, and these give the foot its characteristic elongated form. There are five complete digits, and two tiny bones in each foot marking the position of an extra toe which, like the thumb, is never visible externally.

THE NERVOUS SYSTEM.

The brain is about an inch long. Looking at it from the dorsal surface, we see in front two large swellings, which give off nerves to the nostrils. Next are the large, paired lobes of the cerebrum, and behind them, almost covered by two large lobes, is a narrower part, the thalamencephalon, a very important part of the frog's brain, controlling sight and spontaneous movement. The cerebellum is a very narrow band anterior to the spinal bulb, which narrows behind and is continuous with the spinal cord. The latter passes through the canals in the vertebræ, and gives off pairs of spinal nerves along the length of its course. The branches of these nerves pass to all parts of the body.

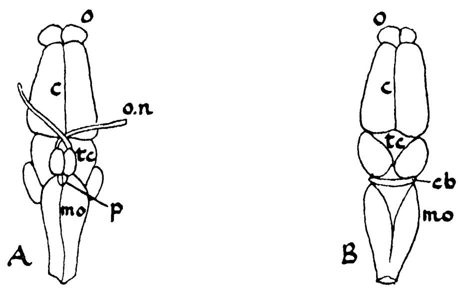


FIG. 50.—BRAIN OF FROG. × 1⅓.
A. VENTRAL SURFACE. B. DORSAL SURFACE.
o, Lobes connected with nostrils; *c*, Cerebrum; *tc*, Thalamencephalon; *cb*, Cerebellum; *mo*, Medulla oblongata (spinal bulb); *p*, Pituitary gland; *on*, Optic nerve leading to eye.

To keep frogs or toads for observation, make them a home in a large, shallow wooden box. Line one half with soil and plant tufts of grass in it. Drill holes in the bottom of the box to allow for drainage when the grass is watered. The animals should not be kept long enough to allow the wood to rot. In the other half of the box place a large flower-pot saucer or glazed pie-dish containing a little water and some water weeds. Cover the box with a piece of netting, muslin, or perforated zinc. Keep only two or three frogs at a time, and supply them with fresh food every few days, removing any that becomes stale. Small earth-worms, caterpillars (not the hairy variety), "gentles", and flies may be given to them. Take them back to the pond when you have kept them for a few weeks. For newts, make a case to fit over your large glass aquarium. The framework may be of wood, the roof of perforated zinc, the sides of glass, and the floor partly covered with perforated zinc. On the floor scatter stones and water plants, and fix something (a piece of bark from a florist's shop is admirable) to form a gangway between the floor of the cage and the surface of the water beneath. This arrangement will enable tadpoles to leave the water when they are ready, so that the newts can live either in the water or out of it.

The Snake

In the same type of cage as you have made for the frog you can keep snakes. A small grass snake is the best kind to keep for observation. Grass snakes are quite common in most woods and forests, and can be distinguished from adders by their shape and marking. They are long and tapering, with the dorsal surface coloured olive-grey to dark brown, with black spots and narrow cross bands, and a grey or greyish-black ventral surface. Adders, however, have blunter bodies, a distinct neck, and a reddish-brown dorsal surface, marked along the back in a zigzag, diamond-shaped pattern, with a dark cross or "V" on the head. Older snakes feed on frogs, mice, and fishes, but young ones will eat earthworms.

Look at the body of the grass snake. It is long and slender, and covered with horny scales, differing from those of the fish in being produced by the epidermis. Those on the head are larger and do not overlap, while on the ventral surface are specially strong ones, whose use you will discover later. The skin is dry, for there are very few glands. Sometimes, in a wood, you may find a snake's skin, or slough, for this is shed as a whole, and in the rattlesnake, the rattle, which is at the tail end of the animal, is increased in size by the remains of successive sloughings. Many of the poisonous snakes are brightly coloured, and these are found mostly in the tropics.

The grass snake has a small, narrow head and no neck. Try to find ears, and observe the eyelids carefully. There are no external ear openings, but the ears open internally into the throat. The eyelids are immovable, and this fact is responsible for the staring effect of the eyes. The nostrils are just above the mouth. Notice the rapid flicking out of the tongue, which is long, narrow, and forked at the tip, and is used as an organ of touch in much the same way as the cat uses its whiskers. The tongue of a grass snake twenty-two inches long was found to measure nearly two and a half inches. It is protruded through a gap in the front of the mouth where there are no teeth, these being found at the sides of the jaw, where they are fixed very firmly and not embedded in sockets. On the roof of the mouth in many snakes are special teeth, each of which is rolled lengthwise so that its edges meet and form a groove or canal. These are the poison fangs, and at the base of each is found the poison gland. When the mouth is closed, the fangs point backwards and lie along the roof, covered with a fold of skin, but the opening of the mouth causes them to become erect, enabling them to

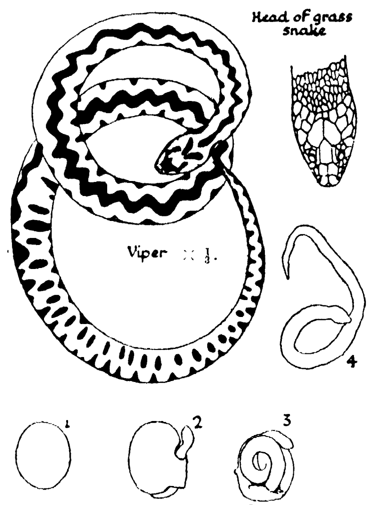


FIG. 51.—STAGES IN DEVELOPMENT OF EGG OF GRASS SNAKE.

pierce the skin of the victim. At the same time muscular pressure is exerted in the poison glands and causes the poison to flow along the canals, whence it passes into the prey. Should a fang become broken, it can be replaced by another from behind. The poison teeth of harmless snakes, like the British grass snake, are not grooved, and the gland is an ordinary salivary gland.

Watch the movements of the snake as it glides along. Apparently it has no limbs, and there is no slimy substance secreted by the skin to enable it to adhere to or slip over any surface. On the ventral surface there are no tiny hairs like those we find in the earthworm to enable it to grip. Then how is it possible for the snake to move with such great rapidity? Lie down flat on your face and, keeping your arms to your sides and your feet together, try to move forward. You will find it very difficult, until you press hands and feet against the floor, using them as levers to propel the body. The snake uses its ribs in much the same way as you would use your hands and feet to get along by this method. Its backbone is extremely flexible, and is made up of a great number of vertebræ specialised in shape to allow of the greatest possible bending. In the python there may be as many as four hundred separate vertebræ. They may be divided into trunk vertebræ and tail vertebræ, and each trunk vertebra, except the first, the atlas, bears a pair of fine ribs. These are attached to the ventral scales, and are used as organs of locomotion. When the snake moves along, the scales grip the ground, and the body is pushed forward by powerful muscles, so that the snake may be said to row on the earth, using its scales as the blades of oars. As the ribs are attached to the scales, they move with them, and the specialised vertebral column being able to withstand the pressure exerted on it by the movement of the ribs, moves too. The muscles between the ribs draw the ribs together first on one side of the body and then on the other, so that the snake moves by looping its body sideways, and not up and down as in the looping geometer caterpillars. The snake can also swim by graceful, undulatory movement. There are no limbs and no limb girdles in most snakes; a few have traces of a pelvic girdle only. Think of the advantages of this supple, elongated, limbless body in creeping through cracks and holes and gliding between stones and boulders.

If you look at the size of a grass snake's head and compare it with the size of an ordinary frog, you may wonder how it is possible for the frog to be captured and eaten by the snake, which has no limbs to hold it or pull it to pieces. The snake always swallows its food whole, and may first paralyse it by use of the poison fangs. It is then gripped firmly between the jaws, which are capable of great extension, owing to the fact that the two halves of the lower jaw are joined together in front by elastic ligaments and several of the bones of the upper jaw are movable. Thus the mouth cavity is capable of considerable enlargement, and by the alternate moving forward of first one half of the lower jaw and then the other the mouth and throat are gradually pulled forward over the bulky food. Some egg-swallowing snakes have very poorly developed teeth in the jaws, but this is compensated for by the extra development of some of the narrow spines of the vertebræ, which bulge into the dorsal wall of the gullet and pierce the egg-shell with which they come into contact. It is quite amusing to watch the sudden collapse of the egg. The food is dissolved by the digestive juices, and as the alimentary canal is much elongated, owing to the length of the body, digestion is a somewhat lengthy process. The cloaca provides a means of escape for the excretory and reproductive products, as it does in the frog, and is found on the ventral surface near the posterior end of the body, marking the division into trunk and tail. As the tail of the grass snake is longer than in the adder, the cloaca is found farther forward in the former. Near it may be found, in some snakes, the openings of two glands, the odoriferous glands, which secrete a strong-smelling liquid, and may be used to keep away enemies.

How does the snake manage to breathe while it is in the act of swallowing? The opening of the long windpipe is far forward in the mouth, and the glottis can be protruded between the tips of the lower jaw, so that it is not completely blocked by the contents of the mouth. The inspired air passes through the trachea into the lung, the right lung being usually the only one developed. In some snakes there may be a very small left lung, but owing to the elongation of the body the paired internal organs are not arranged symmetrically, and one of the pair may be smaller or even lacking. The lungs expand and contract as the pressure on them is alternately decreased and increased. This is brought about by the movement of the muscles between the ribs, which contract and pull the ribs into a more vertical position. As the ribs usually slant towards the tail end, this movement increases the diameter of the body cavity, thus lessening the pressure on the lung and allowing it to expand. Exchange of gases takes place in the capillaries round the air sacs, and the relaxation of the muscles between the ribs causes increased pressure on the lung, and so the air is forced out again. Pure blood from the lung is conveyed to the heart, which is three-chambered, the one ventricle being incompletely divided by a partition. Thus the pure blood is never completely separated in the heart from the impure blood, and the snake is cold-blooded.

The sexes are separate, and grass snakes pair in early summer. After fertilisation, the female lays about thirty soft eggs, which are tough-shelled and about one inch long. They are laid usually in a mass of decaying matter, where they are left to hatch. In early autumn, the fully developed snake breaks through the shell, piercing it by means of a special "egg tooth" in the front of the jaw. This tooth is subsequently shed. Many snakes lay eggs with hard, chalky shells, while others, like the adder, develop within the mother and are then born. In all cases the young resemble their parents, that is, there are no larval stages like we find in the frog.

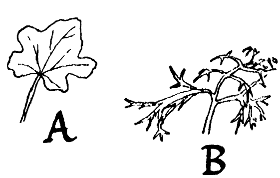
In the winter, snakes hibernate in fairly deep holes, and reappear with the warmer weather in the spring.

Water Plants

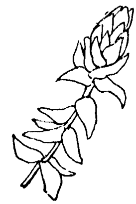
From what we have learnt about animals of the aquarium, we find that all are specialised in one way or another for life in the water. Among their special features we notice, in the case of insects, the breathing organs and legs adapted for swimming, the gills and the streamline shape of the body of fish, and the fish-like characters of tadpoles. Water plants may also show special characteristics. Like the water animals, the water plants have to breathe the oxygen dissolved in the water, but the amount of free oxygen in water is much less than in air, so that the submerged parts require increased breathing surface. They are covered with a thin, permeable outer skin, so that water can pass freely through the external cell walls of the whole surface. The water which enters the plant contains a large quantity of carbon dioxide compared with that in air, and during the breaking up of the carbon dioxide and the formation of carbon compounds a large quantity of oxygen is produced. This does not escape, but fills the air spaces, which are very large and numerous in aquatic plants. From these spaces the gas passes slowly to every cell. The air also helps to make the plant buoyant, so that it does not sink easily.

The water lily has leaves, and the duckweed has leaf-like stems or fronds, floating on the surface of still water. Water lily leaves have on the upper surface a very thick skin covered with wax, which gives it a polished appearance and prevents it from being wetted. The wax does not cover the breathing pores, which we find as usual on a surface exposed to the air. Duckweed fronds have a hairy surface which acts like that of the water spider in keeping a layer of air close to the skin, and so preventing it from becoming wet. The bladder-wort, a plant with no roots and found growing in deep pools, floats freely on the surface by means of bladders found at the ends of narrow, elongated leaves on the root-like stems. These bladders are also provided with tiny openings through which small animals can enter but cannot escape. They die and decay in the bladder, and the plant absorbs the juices produced.

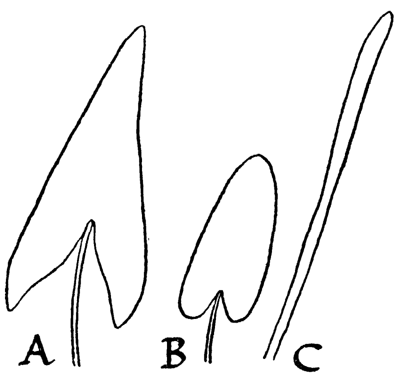
Only plants which float entirely, like the bladderwort, can live in deep water. Around the water's edge we find plants like arrow-head and water crowfoot, which send roots into the soil. As the leaves and stems need light and air, such plants



LEAVES OF WATER CROWFOOT. $\times \frac{3}{5}$
A. Aerial. B. Submerged.



ELODEA. $\times 1$
(Canadian Pondweed).



LEAVES OF ARROW-HEAD. $\times \frac{1}{8}$
A. Erect. B. Floating. C. Submerged.

FIG. 52.

could not grow in deep water. The roots, however, are not well developed, and serve merely to anchor the plant. The roots of duckweed are not attached to the soil, but hang freely in the water from the under surface of the stem; they act partly as organs of absorption and partly as a keel by keeping the plant properly balanced.

Floating leaves, such as those of the water lily, are usually entire, with the petiole attached near the centre, so that the pull on the leaf acts centrally and keeps the lamina flat on the surface. Submerged leaves, on the other hand, are usually long and strap-shaped, like those of the pondweed, or may be cut, like water crowfoot leaves, into numerous narrow divisions. Such leaves provide a greater surface for the absorption of water containing the necessary dissolved salts and gases. Also, in plants living in running water, the leaves turn readily with the current, and so are not torn easily. Water crowfoot has both submerged divided leaves and aerial entire leaves, while in the arrow-head are three types of leaves, the aerial ones shaped like arrow-heads, floating heart-shaped leaves, and submerged ribbon-shaped forms.

Water plants usually increase rapidly in size and number, owing to the abundance of salts in solution in the water. Owing to such rapid growth, many of them reproduce chiefly by the breaking off of branches, which continue to grow and produce new plants. The Canadian pondweed, *Elodea,* in Britain reproduces entirely by this method, for only the female plants are found here. A few branches placed in the aquarium soon produce many more. When flowers are developed, they usually appear above water-level so that pollination may take place. After pollination the flower head may bend over and carry the developing fruits under water. Many plants growing by the water-side produce fruits which float easily and so are distributed by water. Flowers of the pondweeds are pollinated by the wind; those of the water lily and water plantain by insects. *Vallisneria,* an interesting plant which lives well in an aquarium, produces seed-bearing flowers on one plant and pollen-bearing flowers on another. The female flowers grow each at the end of a spirally coiled stalk, which may reach a yard in length and pushes the flower up above the surface of the water. When the water-level rises, the stalk uncoils and raises the flower, so that it is always above water. Each male flower has two stamens, is very small, and hundreds of flowers are produced in a short-stalked inflorescence. When ripe, they break off and rise to the surface of the water, where they may meet female flowers, and pollination takes place. The spiral stalk then contracts, dragging the pollinated flower down to the bottom of the pond, where the fruit ripens.

What happens to water plants in the winter? Some of the pondweeds have at the bottom of the pond a creeping stem which remains alive after the death of the leaves and sends up new leaves in the spring. Other plants, such as bladderwort and Canadian pondweed, have winter buds. These buds are produced in autumn, and consist of closely packed leaves filled with reserve food material in the form of starch. When the rest of the plant dies, the buds fall to the bottom of the pond, where they remain until the increase in temperature in the spring causes them to rise again to the surface and grow into new trailing stems. In autumn the whole duckweed plant often becomes filled with starch and sinks to the bottom.

EXERCISES

1. Place sticklebacks, some in white dishes containing water and food, and an equal number in black or dark-coloured dishes. Keep all the dishes under the same conditions. Notice any differences between the fish at the end of a week. Transfer equal numbers from each dish to fresh dishes of the other colours. Keep a record of the appearance of the fish in each dish.

2. Make an enlarged drawing of the stickleback to show general body shape, fins, spines, scutes, position of mouth, eyes, and gill slits.

3. Examine the gills of a herring. Lift up the operculum with a needle and note the arrangement of the gill arches inside. Gently push a blunt needle between a pair of arches through to the mouth. Carefully cut away the operculum, and remove one gill. Make drawings to show gill filaments and rakers.

4. Cut carefully along the mid-ventral surface of a herring, from mouth to anus. Note the arrangement of digestive organs, and make careful drawings.

5. Watch the movement of the operculum in the stickleback during breathing. Count the number of times it rises per minute, and compare the stickleback with any other fish you can watch.

6. Look at as many fishes as you can and note the position of the fins. Make drawings of a fish, showing—

(*a*) The dorsal fin, cut into parts.
(*b*) The pelvic fins anterior to the pectoral fins.
(*c*) A symmetrical caudal fin.
(*d*) A caudal fin with larger dorsal lobe.
(*e*) A caudal fin with smaller dorsal lobe.

7. Draw the different stages in the life history of a frog.

8. Put a few newly hatched tadpoles with some water weeds in a white saucer in a shady place, and look at them with the aid of a lens each day.

9. Take four dishes of equal size and in them place respectively one, five, ten, and a much larger number of tadpoles. See that all are kept under similar conditions, and notice the growth and development.

10. Compare the development of tadpoles kept in a warm place with those in a colder one. Take care that all other conditions are equal.

11. Keep tadpoles in dishes of different colours, and note whether the animals are affected at all.

12. Make drawings to show the differences between the fore limbs of a male and a female frog. Examine the frog carefully, and make a sketch of the whole animal. If you can get a dead frog, open the mouth and try to find vomerine teeth, internal openings of the nostrils, and the glottis.

13. Watch a grass snake as it darts out its tongue. Compare the size and shape of dorsal and ventral scales.

14. In autumn look for the winter buds of *Elodea* and bladderwort; they are easily distinguished by their bright colour compared with that of the rest of the plant. Keep some in your aquarium, and watch their development in the spring.

EXERCISES AND QUESTIONS

1. Describe any characteristics which fit fish for life in the water.

2. Compare the shape of the fish with that of a boat. Name the parts, if there be any, which correspond to oars, keel, and rudder.

3. Describe the movements that a fish makes when it swims.

4. A fish scale shows twenty rings. How old is the fish?

5. Make two lists of fishes—

(*a*) A list of those laying few eggs.
(*b*) A list of those laying innumerable eggs.

How do the eggs of (*a*) differ from those of (*b*) in appearance, the place where laid, the time taken to hatch, and the form of the young fish immediately after hatching?

6. Do ponds, rivers, or seas ever become overstocked with fish? What reasons can you give for your answer?

7. What are the uses of gills and fins to the fish?

8. Compare the breathing organs of fish, tadpole, and frog.

9. Why does a dead fish float upside down?

10. Where is the lateral line in a fish, and what are its uses?

11. Describe the stickleback's nest. Which parent makes it, and how is it made?

12. Compare the gills of a fish with those of a tadpole.

13. Describe the changes that take place in frog's spawn before the tadpole escapes from the egg.

14. What are the uses of the gelatinous egg coverings?

15. Describe the development of the tadpole and its change into a frog.

16. How does a frog catch its prey? Describe the method employed in swallowing the food.

17. Why is there such a marked difference in length between the hind and fore limbs of the frog and toad, but not in the newt?

18. Compare the characteristics of fishes and amphibians.

19. What are the differences between a fish and a tadpole?

20. How does a frog breathe, and why does it breathe more slowly than a cat?

21. Why is the frog a cold-blooded animal?

22. Where are the fat-bodies in a frog, and what are their uses?

23. A snake has no limbs, yet it moves very rapidly. Why is this?

24. How is it possible for a snake to swallow an animal or an egg which is much broader than itself?

25. Where are the fangs in a poisonous snake? Say how they are used.

26. In what ways do water plants differ from land plants?

27. Account for the differences in shape of the leaves of the arrow-head.

28. Why are rooted plants not found in very deep water?

29. Describe the methods of reproduction amongst water plants.

30. Why is it necessary for water plants to be able to breathe over their entire surface?

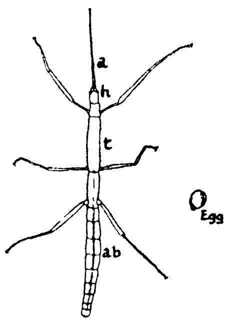
CHAPTER VIII

HOW TO KEEP INSECTS

The Stick Insect

A SUITABLE insect to keep in captivity is the stick insect. It is not a native of Great Britain, but lives in the South of France and warmer countries. It must therefore be kept indoors, and a simple cage of the type shown in Fig. 53 can be made for this purpose. It should be fairly large, not less than twelve inches high. The supports and floor are of wood, one of the sides or the top of perforated zinc, and the rest of glass. Why should not the whole cage be enclosed in glass? In the floor is cut a circular hole in which rests a small glass pot containing water, and in this a supply of the necessary food can be kept fresh. A layer of soil, about an inch deep, covers the floor, but if the cage be tall enough, a flower-pot containing damp soil in which the food plant is growing will serve the purpose.

Stick insects feed on privet, and fresh supplies of this common shrub must be placed in the cage every week. Watch the insects as they feed, and note the way in which they bite out crescent-shaped pieces of leaf by means of the strong jaws. Notice the well developed eyes, jointed body, long, delicate antennæ, and three pairs of jointed legs each terminating in a pair of hooked claws by means of which the insect clings firmly to any support. When you remove an insect, notice the movement of the legs and suggest why the name of "stick insect" has been given. The three segments bearing the legs together form the thorax, and in each leg the last five segments farthest away from the body together make up the foot. The remaining body segments, numbering eleven, of which only nine are visible, form the abdomen. On either side of each segment of the abdomen may be seen a small protuberance in which is the spiracle. The breathing tubes branch into every part of the body, and their elastic walls are strengthened by strong bands arranged spirally, in much the same way as hose pipes are strengthened by spirally arranged metal wire. These thickenings keep the tubes distended, and the walls may be compressed by means of special muscle fibres. The



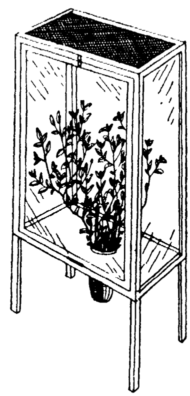


FIG. 53.

STICK INSECT. × 1⅓. AND EGG. × 1.
(dorsal view)

a, Antennæ. *h*, Head.
t, Thorax. *ab*, Abdomen.

INSECT CAGE
(much reduced).

alternate compression and relaxation causes air entering the spiracles to flow through the breathing tubes to all parts of the body, and thus the insect has a very efficient breathing system.

The insects usually kept in museums, or obtained from live-stock dealers, are females, and new individuals are produced from unfertilised eggs, for males are very rare. Egg laying begins in June or July, and continues sometimes till Christmas; during that period seven insects have been known to produce between them over four thousand eggs. The eggs are dropped on the soil, and very closely resemble seeds. Each is ovoid, and is enclosed in a tough brown skin bearing at one end a tiny protuberance, looking like the scar on a seed. The skin is a capsule surrounding the true shell of the egg, which is white and tough. The time taken to hatch varies, in some cases being as short as two months. Unlike most very young insects, which are larvæ, the young stick insect is exactly like its parent, and often carries with it for the first few days the empty egg-shell and capsule attached to one of the hind legs. It begins feeding soon after it has hatched, and as it grows it frequently moults. If you can watch the moulting taking place, you may find that the insect often leaves behind in its old skin part of a leg, the stump of which will in time grow into an ordinary leg again. This power of regeneration of lost parts is possessed by many of the lowly-organised animals, by some insects, and by the crayfish, but is lost by the majority of higher creatures. The stick insect has been known to consume its skin after moulting, but this is a very rare occurrence. Usually, after egg laying is finished, the parent dies, so that the duration of life is not much more than a year.

The Cabbage White Butterfly

This butterfly is very common in early summer, and if two or three specimens be captured uninjured in a butterfly net, and placed in a cage with some pieces of cabbage leaf, they may produce eggs. If you cannot capture any butterflies, look for their eggs, tiny cream-coloured objects laid in clusters of from six to a hundred, each with its long axis perpendicular to the leaf surface of plants belonging to the cabbage family. Keep some of the eggs with the leaf, and in a week or so each will hatch into a tiny, green, slightly hairy caterpillar. The caterpillars feed greedily, tearing the leaf with their strong jaws, and fresh supplies of food must be given to them frequently. As each grows so rapidly, its rather tough skin is shed from time to time. Just before each moult, the new skin grows beneath the old one, which splits along the anterior dorsal surface, and the insect emerges by working the old skin backwards until it is cast off at the posterior end. Moulting takes place five or six times before the caterpillar is full grown, when it stops feeding, and makes its way to a secluded place in order to pupate. The name pupa, which means boy or girl, was given to the insect at this stage because it is an undeveloped adult. The pupa of a butterfly or moth is known as a chrysalis (Gk. *chrysos*, gold), because the chrysalids of some butterflies have golden streaks or markings on them.

The chrysalis of the cabbage white butterfly is found commonly attached to fences, window frames, doors and ledges out-of-doors. When the caterpillar reaches such a place it excretes any food left in the digestive system, its skin becomes darker and wrinkled, and later splits along the mid-dorsal line and liberates the chrysalis. The colour of the new skin is greyish-green marked with black spots. The pupal body is much shorter and broader in the middle than the larval body and tapers at the ends. It is incapable of movement, except for a few segments at the tail end, and is fixed in a vertical position, tail downwards, by means of a silk pad at the posterior end and a silken girdle round the middle. The caterpillar produces the silk from glands in the mouth, and in the butterfly these glands function as salivary glands. Many caterpillars, such as those of the silk-worm moth, spin a complete silken case, the cocoon, around them, while others become covered with a very hard skin and bury themselves in a cell in the ground. The chrysalis does not feed, but remains quiescent while many changes take place in its internal structure, until at last the adult or imago is fully formed. At this stage, the form of the body can be seen clearly through the skin. When ready to escape, the insect ruptures the skin by means of jerky movements of the legs and body. The skin splits along the anterior dorsal surface, and also along the sides, the insect withdraws its legs from their cases and emerges through the opening. The wings look very small, and the butterfly crawls to the nearest support, where it stretches them, holding them downwards to allow the blood to flow into them. By the action of muscles great pressure is exerted on the blood, causing the wings to expand rapidly, until eventually the insect can use them for flight.

The eggs of the cabbage white butterfly are often found as early as April or May; the caterpillars feed during June and July, and the butterflies eventually produced from them lay eggs which give rise to a second generation of butterflies in late summer. The caterpillars of this second brood may continue feeding till November, and the pupal stage lasts throughout the winter, the butterflies emerging in the first warm days of spring. These butterflies can be distinguished from those of the other brood by the greyish-black patches on the tips of the fore wings, these patches being black in late summer butterflies. The wings are white, sometimes tinged with yellow, and occasionally the veins are greenish in colour.

See if you can distinguish the head, thorax, and abdomen of the butterfly. The head bears a pair of large black compound eyes between which, on the dorsal surface, there may be two simple eyes, but even when present they are not easily seen. The antennæ are long, being made up of a varying number of joints, and they are often better developed in the male than in the female. The tips of most butterflies' are usually club-shaped, whereas those of moths' are pointed. The antennæ are very sensitive, probably acting as organs of smell, and can be moved easily by means of special muscles.

The butterfly sucks up its food, consisting of nectar, honey-dew, and the juices of over-ripe fruit, by means of a long, tubular mouth, the proboscis. This is made of two halves, linked together by their thin edges and the hairs fringing them, so that the hollow trough of one half faces that of the other. If the tubes become blocked by pollen or dust, the insect can separate the halves, remove the obstruction by means of its legs and then re-form the tube. Its wall is composed of hard rings separated by softer tissue, so that the proboscis can be spirally coiled like a watch spring beneath the thorax, or extended, when procuring food, as much as several inches in some cases.

The thorax bears three pairs of legs of the usual type, and each terminates in two claws. The legs are used more for supporting the body when at rest than for walking, but when used for locomotion they move alternately in threes, the first and third of one side and second of the other side being on the ground together. If you take two tripods and fit them together, so that an apex of one fits inside the middle point of a side of the other, then the three legs of one tripod represent the legs which touch the ground together. The wings are borne on the second and third divisions of the thorax, one pair to each segment. Each is strong and membranous, and is covered with scales which easily brush off, looking like fine dust in the hand. The scales vary in shape, are very minute, cover the

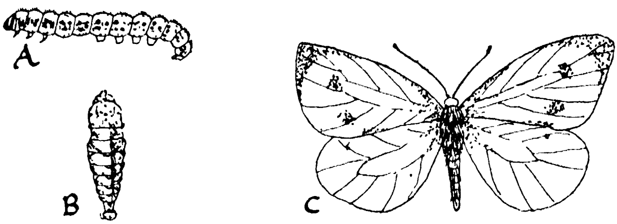


FIG. 54.—CABBAGE WHITE BUTTERFLY. $\times \frac{2}{3}$

A. Larva or caterpillar. B. Pupa or chrysalis. C. Imago.

whole body, including the antennæ, mouth parts, and appendages, and the beautiful colours seen in most butterflies and moths are due to them. In some males the wings may bear special scales which secrete a strong-smelling fluid, useful for keeping away enemies. Notice the "veins," forming the strong framework of the wings.

The abdomen is thickly covered with hair-like scales. All the eleven segments cannot be seen externally, only eight being visible on the dorsal surface of the male, and seven in the female. On the ventral surface one less can be seen in each sex. The remaining segments are tucked away inside the last one. The anus, at the extreme posterior end, and the opening of the reproductive organs on the ventral surface of the abdomen, are not easily seen. The spiracles are found one on either side of each visible segment of the abdomen.

The Currant Moth

The Currant Moth, or Magpie Moth, as it is more commonly called, is a prettily marked insect, with a yellowish body spotted with black, and white wings marked with black, yellow, and orange. It measures nearly two inches across the wings, and over an inch long in the body. The eggs are yellow, and are laid singly or in twos and threes on gooseberry and currant leaves in late summer. The larvæ emerge from the eggs in about ten days, and feed on the leaves. When they are about half an inch long they prepare for the winter by spinning leaves together by means of silken threads and hiding between the leaves. Others may hide just beneath the surface of the ground or in cracks and crevices of walls and fences. In these places they remain during the winter months, and emerge in spring at the time when the bushes are producing their young shoots, upon which they proceed to feed. They may grow to a length of about an inch, and resemble the moths in their coloration. Towards the end of May the caterpillars fasten themselves by means of threads to stems or leaves, or they may crawl under stones or clods of earth, where they pupate, and remain as chrysalids until the beginning of August, when the moths escape from the light-coloured cocoons and begin egg-laying.

Watch the caterpillars of the Magpie Moth, and suggest why they are known as "loopers".

The House-Fly

The house-fly differs from the butterfly in having only one pair of wings, borne on the second segment of the thorax, which is usually much more developed than the other two segments. The head bears a pair of compound eyes, usually larger in the male than in the female. There are three simple eyes arranged in the form of a triangle between and slightly behind the compound eyes. The antennæ situated between its large eyes are three-jointed, with two short segments close to the head and a longer segment bearing a projecting plume or bristle. The proboscis is a very complicated structure, having at its tip two soft lips, and the whole organ is capable of being folded back into a cavity beneath the head. The opening of the proboscis is in direct communication with the digestive organs, so that the food, which is always taken in liquid form, is drawn through the hollow tube of the proboscis into the gullet by means of the pharynx, which forms the sucking apparatus. Each hairy leg is nine-jointed, the five

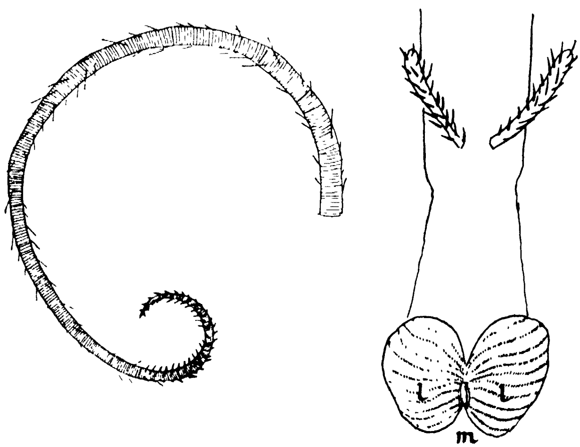


FIG. 55.

PROBOSCIS OF A MOTH SHOWING HARD RINGS (much magnified).

PROBOSCIS OF HOUSE-FLY (much enlarged). *l*, Lips. *m*, Mouth.

segments farthest from the body being regarded usually as a "foot". Each foot or tarsus ends in a pair of claws, between which is a pad, which enables the fly to adhere to smooth surfaces. The wings are membranous, with well marked veins, the arrangement of which is used as a means of distinguishing different species. The wings can be flattened against the dorsal surface, one slightly overlapping the other. In place of the second pair of wings, two tiny delicate organs, the balancers, grow from the third segment of the thorax. Each has a knob at the tip, and is used to balance the insect. Only four of the segments of the abdomen are visible. These are the third, fourth, fifth, and sixth. The next four segments in the female form the egg-laying apparatus, and can be retracted when not in use. Large hairs or bristles are scattered over different parts of the body.

The house-fly lays about a hundred eggs at a time in heaps of stable refuse or other decaying animal or vegetable matter. Each egg is white, ovoid, and about one millimetre in length. From it a tiny white maggot may be hatched within a few hours, or if the weather be cold, in two or three days. The house-fly larva or maggot is quite different from the butterfly larva, having no limbs, no jaws, and no eyes. It is provided with a sucking mouth, by means of which it takes in the food substances by which it is surrounded. After a short period, varying from two or three days to seven or eight weeks, the larva pupates. The pupa case is about a quarter of an inch long, and at first yellow in colour, but later it changes to red, then brown, and finally, just before the fly emerges, to black. The pupal stage lasts for but a week or two, so that a house-fly may develop from an egg in as short a time as nine or ten days. As the female lays batches of eggs continuously during the hotter months of the year, you will understand why swarms of flies appear suddenly in the summer months. The majority of them die from cold at the onset of winter, but during the cold weather many pupæ remain protected and from them flies emerge in early summer.

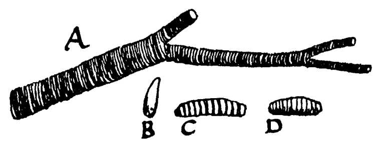


FIG. 56.—HOUSE-FLY.

A. Part of trachea } much enlarged.
B. Egg }
C. Larva. × 1
D. Pupa. × ½

The Hover-Fly

This is a fairly large fly, usually brightly coloured, sometimes banded with yellow on a dark background so that it resembles a wasp or bumble-bee. It feeds on pollen, and gets its name from the fact that it may often be seen rapidly vibrating its wings and hovering over a flower. The common hover-fly lays her eggs on plants, where the larvæ feed on aphides and other insects. One species enters ants' nests and deposits her eggs in the soil at the bottom of the nest, where they hatch and the larvæ act as scavengers, feeding on the waste matter excreted by the ants. Others lay eggs in stagnant water, in rotting wood, in fungi, and in other places where there is an abundance of decaying material that the larvæ may use as food.

The larva that hatches from eggs laid on leaves and twigs of land plants is slug-like in appearance, with a soft body and no legs. It may be light green or red with darker spots or stripes. It has the power of changing its shape, as, with its broad posterior end fixed to a leaf, it flings about the narrower anterior end as though in search of food. When full grown, the larva pupates near the place where it has been feeding. The posterior end of the body is fixed to a leaf or twig by a secretion from the anus, and the larval skin forms a case round the pupa in much the same way as in the ladybird. The colour changes to dark brown, and eventually the pupa case splits and the hover-fly emerges. Hover-flies, which resemble bees and wasps, may easily be distinguished from them by possessing only two wings.

The Leather-Jacket

The larva of the crane-fly, or daddy-long-legs, is known as the leather-jacket because of the tough nature of its greyish-brown skin. When full grown the larvæ measure over an inch in length, and may be found just under the surface of the soil, where they feed on the roots of grasses, especially of wheat and other cereals, thus causing much damage to crops. They are legless, but can move fairly rapidly by means of powerful muscles in the body wall. The development of the larvæ may be watched if one or two are captured and kept in a large insect cage where grass is growing. During development, the larva moults several times, and when full grown makes a cell or chamber in the soil, in which it pupates. In the pupal stage, the wings, legs, antennæ, and mouth parts can be clearly seen folded against the body. In spring, when the fly is ready to escape, by means of sharp spines on the abdomen the pupa wriggles out of the cell to the surface of the ground, so that the fly emerges into the open air. The body is long, and the legs extremely long-jointed. The female lays her black, spindle-shaped eggs on the ground or just below the surface. The larvæ which hatch from the eggs become full grown in a few months and develop into adult flies in late summer. The larvæ hatched from the eggs of these change into pupæ at the end of autumn and remain in this state during winter.

The Honey Bee

The honey bee belongs to the order of insects which includes wasps and ants. In each of these insects we find three forms developed, the female or queen, the male or drone, and the worker, a female usually incapable of producing eggs or young.

The body of the honey bee is hairy, the hairs varying in shape and size according to the purposes for which they are used. The head bears two long, delicate antennæ with thirteen segments in the male and twelve in the female. The compound eyes are largest in the drone, where each occupies the greater part of the side of the head, and between them are three simple eyes. The biting mouth parts are best developed in the workers, who use them in building the comb. As they are not used for ordinary biting purposes, they are not as well developed in the queen and the drone. To reach the nectar stored in long-tubed flowers, the honey bee has a long tongue. This is curved to form a hollow tube, open along the mid-ventral line, covered with hairs, and swollen at the tip into a small, spoon-shaped lobe. The ventral opening of the tube can be widened and the tongue curved in the opposite direction when it requires cleaning. Two mouth parts, one on either side of the tongue, can fit round it to form a long air-tight tube, the proboscis, through which nectar is sucked up by the action of pharynx and stomach. When not in use, the proboscis can be turned back and sunk into a groove on the ventral surface of the head.

The thorax bears the three pairs of legs. These are covered with hairs, which may be simple or branched. The foot, as in the fly, is made up of five segments with two claws, one on each side of a median pad at the tip. One joint of each of the first pair of legs bears a projection which fits into a rounded cavity in the next joint. This cavity is set with fine teeth

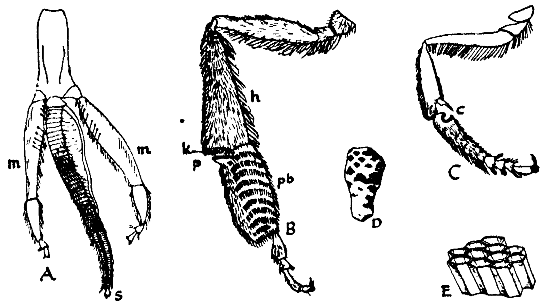


FIG. 57.—THE HONEY BEE.

A. PROBOSCIS (much enlarged)—The tube-like tongue is shown slightly flattened at its base. *s*, Spoon-shaped lobe; *m*, Mouth parts helping to form the proboscis.

B. HIND LEG (inner surface)—*h*, Hairs used for removing pollen from brush; *pb*, Joint bearing pollen brush; *k*, Hairs fringing pollen basket; *p*, Pincers which nip the wax plates in comb.

C. FIRST LEG—*c*, Comb for cleaning antennæ.

(B and C: much enlarged.)

D. QUEEN CELL. × ½ E. WORKER CELLS. × ½

arranged like a comb, and the whole apparatus is used in cleaning the antennæ, which are repeatedly passed through it. Each of the legs of the third pair in the worker bears on one of the joints nine rows of short stiff hairs, forming a brush with which the bee collects pollen scattered over the hairs of the body. When a quantity of pollen has accumulated on the brush, the bee crosses its hind legs, each of which removes the pollen from the opposite leg by means of strong bristles fringing one of the joints. The outer surface of the joint bearing the bristles is flattened and hollowed, and serves as a basket to hold the pollen from the brush. The pollen-basket is fringed with long, curved hairs, helping to keep in place the pollen mass, which is patted down firmly in the basket by the middle pair of legs. When the bee reaches the hive, the pollen mass is removed from each hind leg by a spur on the middle joint of the leg and is stored in cells as "bee-bread".

At the base of each of the two pairs of membranous wings is a spiracle. The wings are largest in the drone and smallest in the queen.

The abdomen has six visible segments in the queen and worker and seven in the drone. Every segment but one bears a pair of spiracles. At the posterior end of the queen's body is the egg-laying organ, and connected with it is the sting, a hollow tube formed by three pieces surrounding a canal. The surrounding sheath holds in position the stylets or lancets, which are barbed at the tip, and move up and down usually within the sheath. When the bee stings, the sheath and its stylets pierce the skin of the victim, poison flows through the canal of the sting from a poison sac at its base, and enters the wound. In the worker and drone there is no egg-laying organ, and the sting is better developed than in the queen. The worker usually loses the sting and part of the gut after use, and consequently death results. Wax glands are situated on the fourth, fifth and sixth ventral segments of the abdomen of the worker. The wax is secreted as a fluid which hardens into thin plates. These pass out between the segments and are removed by spines on the hind legs. The legs are then bent forward and the wax is seized by the biting mouth parts and kneaded into the required condition for building cells.

The male is the largest form of honey bee, and can be recognised by the large eyes, which nearly meet in the mid-dorsal line of his head, while the queen is distinguished by her long abdomen. The workers build the comb, and a colony of bees in spring consists only of workers and a queen. The cells are made of wax, and are arranged in vertical combs, each made up of two layers of cells placed back to back, so that their open hexagonal ends face outwards and their long axes are nearly horizontal. The cells are tilted slightly with their open ends upwards to prevent the escape of honey. The queen lays an egg in each cell, and the first laid eggs, which change into workers, hatch at the end of three days, into tiny, white, legless larvæ. These are then fed for three days on special royal food, made by the workers from honey and pollen which has been partly digested and then returned to the mouth. The workers next fill the cells with pollen, honey and water, and on these the larvæ feed until they are full grown, when each cell is closed by a lid made of pollen and wax. Within the enclosed cell the larva pupates, until, about three weeks after the egg is laid, a fully formed worker bee emerges. These young workers remain in the hive for a few days, helping to feed the larvæ, then they fly out and collect pollen and the nectar from which they make honey to be stored in the hive for food. The cells from which drones emerge are slightly larger and have a more rounded opening than those which house workers. The development of drones from eggs takes about twenty-four days, and the insects do not help at all in the work of the hive. Later, the workers build at the edge of the comb a few very large, irregularly shaped cells in each of which the queen lays an egg, and when the larvæ are hatched, they are fed entirely on "royal food" until they are fully grown and change into pupæ. About fifteen days after the egg is laid a young queen bee is ready to emerge from the cell. Sometimes before emergence takes place, the existing queen, accompanied by many of the workers, may leave the hive and begin a new colony elsewhere. The first young queen to leave a cell, followed by the drones, leaves the hive on her "nuptial flight," and eventually returns after having received a large store of spermatozoa from a drone, which subsequently dies. She then proceeds to sting to death any inhabitants of queen cells. Occasionally, however, the old queen does not leave the hive until after the young queen has returned from her nuptial flight and killed the other developing queens. The young queen then begins egg-laying and continues throughout the summer and early autumn. With the onset of winter, the workers gnaw the wing bases of the drones and push them out of the hive. Thus disabled, they are prevented from returning for food and shelter, and so die of starvation and cold. The workers then retire into the hive, where, during the winter, they feed on the honey stored in the cells inside the upper part. With the return of warm weather in the spring, some of the bees may leave with the old queen and swarm, leaving some with the new queen in the hive.

The Social Wasp

Social wasps live in a colony very similar to that of honey bees. In spring the queen, who has been hibernating (L. *hibernus*, wintry) during the winter, leaves her retreat, and searches for a suitable place in which to make her nest. She may choose the discarded burrow of a field mouse, or other small tunnelled chamber in the soil, and may be seen continually flying round the opening, as though making sure of her bearings. She then flies into the tunnel, and scoops out a small hollow or cavity at its extremity, bringing the soil a little at a time to the surface. When this is finished, away she flies to the nearest fence, and by means of her powerful "jaws" scrapes away a small portion of the wood, returning with it to her nest, where she chews it well, mixing it with saliva and changing it into wasp paper. She fixes the wasp paper firmly to the roof of the nest, often attaching it to small roots, and continues the process until a small disc is formed. From this disc she suspends a vertical column about as long as her body, and at the lower end of the column constructs four small cells with hexagonal openings facing downwards. In each cell she lays an egg, and from this, after about a week, is hatched a tiny legless larva. The queen continues building until about two dozen cells are formed, and when the larvæ appear she feeds them on the juices of green-fly, caterpillars and other insects. The posterior end of the body of the larva remains in the egg-case, which is fastened to the upper part of the cell, and in this way the larva is held in its cradle. When full grown, the larva spins a silken cocoon which lines the cell and then closes it at the lower end with a covering of silk. Within the cocoon the pupa is formed, and about a month after the egg was laid, the fully formed wasp bites through the cocoon at the upper end, and crawls from her cell on to the comb. The first wasps to hatch are the workers, and they immediately set to work to enlarge the nest by scraping away the surrounding soil, carrying it to the entrance of the tunnel and depositing it on the surface of the ground. The workers now add new cells to the small comb made by the queen. Narrow columns are formed hanging down from the first comb, and these support a second comb. The cavity is lined with layers of wasp paper to make it watertight, a small hole being left at the base to form an entrance to the nest. Additional combs are built below the others, until the nest may contain seven or eight. The original cells from which the first workers emerged are used for egg-laying again, until after three successive wasps have emerged, when the cells are discarded and usually destroyed. From slightly larger cells the drones escape during August and September, and in the lowest combs are found a few larger cells in which queens develop. The queens are much larger than the drones and workers. The males may be distinguished from workers by having one more visible segment of the abdomen and an extra joint in each antenna. All forms feed on ripe fruit juice and other sweet and sticky substances. The young queens mate with the drones in late autumn, and in the cold weather leave the nest and settle in nooks and crannies in sheltered places, where they remain during the winter. The rest of the inhabitants of the nest, with the exception of the queen, perish,

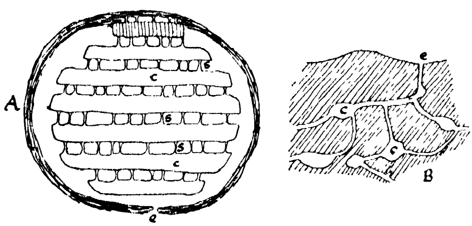


FIG. 58.

A. DIAGRAM OF WASPS' NEST. × $\frac{1}{10}$

c, Comb; *s*, Supports of comb; *e*, Entrance to nest.

B. DIAGRAM OF ANTS' NEST.

e, Entrance to tunnel. *c*, Chamber.

the workers devouring any larvæ developing during late autumn. With the return of warmer weather in spring, the queens emerge from their hiding-places to find suitable sites for nest-building.

Solitary wasps do not live in colonies, but build small mud cells in which the eggs are laid, and line the cells with paralysed caterpillars or spiders. There are only two forms of these wasps, male and female.

The Ant

Like wasps and bees, ants are social insects, living in colonies. The nest consists of numerous tunnels in the soil, and at the end of each is a small cavity in which the eggs are laid. When a queen is about to build a nest, she digs out a small chamber in the soil, where she remains for several months entirely closed in. During this time, until the eggs are laid, she lives on the fat stored in her body, and when the larvæ appear, she feeds them on a secretion of her salivary glands until the pupæ are formed. When the worker ants emerge, they dig their way up through the soil, and so make the first tunnel leading from the nest. The workers are wingless, and they set to work to excavate more tunnels and chambers until a complicated network is formed. Often the soil dug out is carried to the surface of the ground and piled up over the entrances to the underground passages; in some cases it may be carried and deposited some distance away from the nest. Other ants add to their pile of soil leaves, pine needles and other fragments, so making it into an ant-hill penetrated by more tunnels and chambers. In some chambers the queen lays eggs, and when the larvæ are hatched out they are fed by the workers on the juices of insects and "honeydew", a sticky, sugary liquid, secreted by green-flies or aphides. In nests of many kinds of ants, various insects, such as the larvæ of the hover-fly, may be found, and these may serve some purpose in the life of the inhabitants. "Enemy ants", captured from neighbouring colonies, may also be found in the nests. Towards late summer, males and young queens appear, and these both are winged, but the queen may be distinguished by her longer body and shorter antennæ. On a warm day at this time of the year, a swarm of ants, consisting of a young queen surrounded by drones, may be seen making the nuptial flight, during which the queen receives spermatozoa from one drone. The drones then die, but the fertilised queen casts off her wings and begins a new colony. During the winter the colony lives well beneath the surface, the ants rarely leaving the nest, but remaining quiescent in the soil.

An interesting way of watching ants out-of-doors is to insert a sheet of glass vertically in an ant-hill and after a few days to remove part of the hill so that the glass is exposed. Through this you will be able to see the tunnels and chambers and their inhabitants, and on disturbing the ants you will see the workers scurrying to and fro, carrying the pupæ (sometimes incorrectly spoken of as "ants' eggs") into safety. It is fascinating to watch an ant trying to drag to the nest an insect, such as a caterpillar, much larger than itself. If you cannot find an ant-hill to observe, you can make a very simple home for ants by using two rectangular sheets of glass, about eight inches by ten inches. These are separated by thin strips of wood a quarter of an inch thick, and placed along each edge, three strips being of the same length as the corresponding sides of the glass, and the fourth one about an inch shorter. The space between the glass plates is filled with damp soil, and the cell is placed in a large bowl or bath in which a quantity of soil containing ants is also placed. As this soil dries, the ants will migrate to the moist soil in the cell, and the opening can then be plugged with damp cotton wool. When dry, the cotton wool may be removed, and water inserted by means of a pipette or fountain-pen filler, and the wool moistened and replaced.

The Ladybird

The ladybird belongs to a group of insects in which the fore wings form a hard leathery sheath or shield protecting the other pair. Frequently ladybirds may be found in masses, and are brightly coloured little beetles, often with spotted wing covers. The food of these insects consists of green-flies, which do so much damage to the rose-trees and other plants, so, like the hover-fly, the ladybird is useful to man. The female lays her eggs in batches of a hundred or more amongst the aphides on leaves of plants. The eggs are small and yellow, and are fixed perpendicular to the leaf surface in much the same way as those of the cabbage white butterfly. They hatch into larvæ with soft, dark-coloured bodies spotted with white or yellow. They have long slender legs and strong "jaws", by means of which they pierce the bodies of the aphides and then suck out their contents. Some larvæ are covered with spines, while others may secrete a white substance which surrounds the skin and has the appearance of cotton wool. They are nearly as voracious as the adults, and may eat twenty or thirty aphides per day. The larval stage lasts about three weeks, and during this period the larvæ moult four times. When ready to pupate they attach themselves by the tail end to plants, palings or other objects, and become bright-coloured pupæ. Often the larval skin may be found surrounding the pupa or attached to its posterior end. At the end of seven or eight days, the pupal skin bursts and the ladybird emerges.

PRACTICAL WORK.

1. Watch a stick insect as it walks, and find out the order in which its legs move.

2. Watch a stick insect feed. Keep one insect by itself and see if it will eat variegated privet.

3. Keep together the eggs laid by stick insects in one day, and notice how long they take to hatch.

4. Keep half of one day's collection of these eggs in the dark and one in the light, and compare the times taken to hatch.

5. Keep half of one day's collection of eggs in a warm place and the other half in a cold place. Compare the times they take to hatch.

6. Try to watch a stick insect as it leaves the egg, and find out which part emerges first.

7. Keep in very warm places some stick insects which have laid their eggs, and see whether warmth has any effect on the length of life.

8. Keep chrysalids of the cabbage white butterfly separately in boxes lined with different coloured papers. Note carefully the colour of the chrysalis when it is placed in the box, and examine it week by week.

9. Repeat the last experiment, with chrysalids of other butterflies and moths.

10. Make up and carry out experiments to find the effect of light and darkness on the development of the eggs of the cabbage white butterfly.

11. Make up and carry out experiments to find the effect of heat and cold on the development of the eggs of the cabbage white butterfly.

12. Keep pupæ of the cabbage white butterfly at different temperatures, and find out whether temperature has any effect on the type of butterfly produced.

13. Find out whether temperature has any effect on the length of the pupation period of different butterflies and moths.

14. Collect different kinds of caterpillars. Write an accurate description of each, and of the pupæ. When the butterflies or moths emerge draw them and keep a record of their names.

QUESTIONS.

1. Why does the pupal stage in the life history of an insect differ so markedly from the other stages?

2. Describe as many insects as you can which do not pass through three stages in their life history.

3. Is there any justification for the adjectives "busy" as applied to bees, and "industrious" as applied to ants? Is there any reason why these adjectives are not applied to wasps?

4. Name any moth that never in its life history feeds directly on plants, and say what its food is.

5. It is often necessary to kill butterflies and moths. Why is this?

6. Why does a butterfly always lay its eggs on the same kind of food plant?

7. Name any insects useful to man, and say what their uses are.

8. Insects lay hundreds of eggs, but birds lay few eggs. Account for this difference.

9. How would you distinguish between a moth and a butterfly?

10. How would you distinguish a wasp from a bee?

11. How does the hover-fly differ from the wasp?

12. What is a wasp comb? Say how it is made.

13. What is meant by a live-stock dealer when he speaks of "ants' eggs"? Why are "ants' eggs" used as food for fishes?

14. Why are some ants winged and others wingless? Distinguish between the different forms.

15. Describe any insect which spends part of its life history in water and part in air.

16. What are the chief differences between aquatic insects and land insects?

17. Give an account of the mouth parts of the housefly.

18. Both the butterfly and the honey bee possess a long proboscis. Compare the use of this in each insect, and say where the proboscis is kept when not in use.

19. Describe the breathing apparatus and method of breathing in land insects.

20. What is meant by "regeneration of lost parts"? Make a list of animals able to regenerate lost parts.

CHAPTER IX

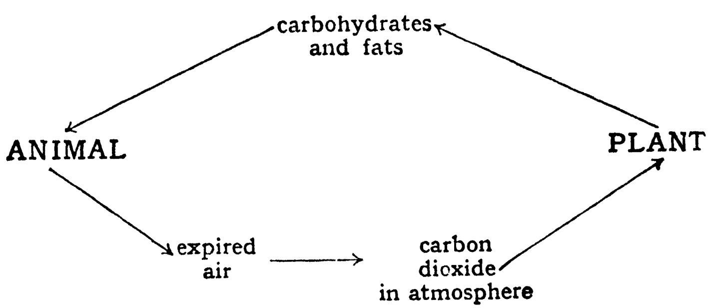
HOW TO AVOID DISEASE

THERE is a true saying about disease that prevention is better than cure, and it is much easier to cure a disease when something is known about its cause.

As all living things feed, health is to a great extent dependent on feeding, and wrong feeding often leads to disease. You have learnt in Chapter I that animals cannot build up their food from simple substances, but take in complex substances, and break them up into simpler ones. Think about the kind of food eaten by animals, and you will realise that their diet differs among themselves. You, for instance, would not grow healthily on worms and insects, neither would a frog thrive well on bread and water, milk and fruit. Yet, although there is this difference in the form in which food is taken in by animals, all need exactly the same classes of food substances in order to be able to build healthy bodies. In Chapter X you may read how many plants store food in the form of proteid, starch and fat, and it is because animals need these food stores that such plants are eaten.

The diet of an animal must contain proteid, fat and carbohydrates (starch and sugar), and smaller quantities of certain other substances. Proteids are complicated substances containing much nitrogen, and some animals obtain them from plant sources such as beans and peas, while others obtain them from animal sources such as meat, milk, eggs, cheese, and fish. Fats and carbohydrates are compounds of carbon, hydrogen, and oxygen. The two latter elements are present in the carbohydrates in the same proportion as in water, whereas in the fats there is a much smaller proportion of oxygen. Starch is the insoluble form in which many plants store food, and from the root tubers of such plants as the tapioca palm, the stem tubers of potato and Jerusalem artichoke, and various fruits such as wheat and rice, animals obtain the largest supplies of starch. Sugar is found in the form of cane sugar in sugar cane and sugar beet, grape sugar in fruit and honey, and milk sugar in milk. Fat may be obtained from seeds of plants, from milk, and many other animal sources.

It will be seen that plants provide all the essential food substances, for they have been built up in the plant body which thus furnishes food for the animal. If we consider carbon, an element absolutely necessary for both plant and animal life, we find that the chief source of carbon for the plant is carbon dioxide, and that carbon assimilation can go on in the plant only in the presence of water and light.[1] The carbohydrates made in the green parts of plants are stored in the form of starch,[2] and to obtain this animals eat the plants. In some parts of the plant, for example the fruit, the starch may have been changed and stored as sugar, and these parts also are eaten by animals. When animals breathe, carbon dioxide is expired, and so animals help to supply plants with their source of carbon. We can thus follow the course of carbon from plant to animal and from animal to plant, and this *carbon cycle* is shown in the diagram:—



[1] Chapter XIII. [2] Chapter X.

An animal needs in its diet certain definite proportions of each kind of food substance. You might be particularly fond of meat, of cake, or of butter, but you could not live entirely on one of these foods. Milk is the only food which contains proteid, carbohydrate, and fat in the proportions necessary for the health of the species of animal which produces it. So young mammals are fed on the mother's milk, and human beings may live for a long time entirely on cow's milk. But the majority of people would tire of a diet consisting only of milk, especially as they would need about two gallons a day. So human beings, like many other mammals, have a mixed diet in order to keep the body healthy.

Most of the foods used by animals contain mineral salts in varying proportions. Thus cheese, eggs, milk, and oatmeal contain calcium salts, without which teeth and bones could not develop properly. The calcium is often in the form of calcium phosphate, which contains phosphorus, an element necessary for the growth of all body cells, but especially for nervous tissues and bones. Iron salts are found in meat, eggs, wholemeal, and some green vegetables; chlorine is an element found in common salt, and salts containing iodine are found in fish, onions, and cod-liver oil. All these salts are necessary to health, and usually the mixed diet consumed by an animal contains a sufficiency of them. You will find in your experiments on the feeding of plants that lack of any one kind of mineral salts, such as those containing iron, causes incomplete development. In the same way, animals do not keep healthy if they lack any of them.

In addition to all these food factors, it has been found that there are other essential ones known as vitamins. Many years ago it was discovered that sailors, who, owing to the length of voyages, fed largely on dried or pickled foods, might have a sufficiently mixed diet and yet not be healthy. They developed a disease known as scurvy, which was cured, however, when fresh fruit and vegetables were added to their diet. Another disease, beri-beri, was found in Japan to affect people who fed on rice from which all the husk had been removed, and when this was added to the diet the disease was cured. More recently it has been discovered that rickets may be caused by a diet in which, though there be the necessary proportion of fat, certain fats are absent. It was, therefore, suggested that all these foods contained extra food factors, vitamins, the different ones being distinguished by the letters A, B, C, D, E. Vitamin A prevents rickets and promotes growth, and occurs in butter, milk, yolk of eggs, and cod-liver oil; it is said to be fat-soluble, because it is dissolved in these fatty substances. Vitamin B prevents beri-beri, and occurs in yeast, wholemeal, to a lesser extent in milk, fresh fruit, and vegetables, and is soluble in water. Vitamin C also is soluble in water and occurs in lemons and most fruits, fresh vegetables, milk, and germinating seeds which have released the plumule. You will notice among the foods in which vitamins A, B, and C chiefly occur that milk will supply all three kinds, and is on this account included in the diet of many animals kept in confinement, or under domestication, for the human animal is not the only one afflicted by the diseases caused by lack of vitamins. Similarly, vitamins D and E are necessary to health, and possibly other kinds may be discovered.

The food we eat should always be fresh, otherwise it may cause disease. Stale food may look or smell offensive, and so be easily recognised and avoided, but often it may be dangerous to eat without appearing or smelling bad. It may contain harmful **bacteria**, such as those producing substances causing ptomaine poisoning. Each bacterium is a microscopic cell, unlike the ordinary typical living cell in that it may not contain a true nucleus. In shape the cells of different kinds of bacteria vary considerably; some are spherical, some rod shaped, and others corkscrew shaped, while others have swollen ends. Some have cilia, others have none, and the cells may be found singly or grouped together in chains. They reproduce very rapidly by simple division, or by the formation of spores, which, being extremely small and light, are easily carried by air and water. Many of them are saprophytes or parasites, stealing their food in many cases from a living host. Some of them, as you may read in Chapter XIII, are useful to man and other animals, but many are responsible for diseases in both plants and animals. The bacterium causing ptomaine poisoning lives in preserved tinned food in the absence of air, and in breaking down complex substances to obtain oxygen it liberates other gases, which gradually inflate the tin containing the preserved food. Such tins can therefore be recognised by their convex ends, and so their contents can be avoided, for not only do the bacteria liberate gases, but in doing so they also produce substances poisonous to man and other animals. Other bacteria cause diseases such as cholera and diphtheria. It is impossible for these "germs" to affect a sound, healthy body, as they cannot live unless they can penetrate into the tissues, where they set free poisons or toxins which get into the blood stream of the animal, and so are carried round the body. Bacteria may be found in soil and in dust; in air and in water. They can live in almost any situation where there is animal or vegetable material for them to feed on.

Many animals are responsible for disease in man, some directly by living in him, and others indirectly by producing poisonous products in the food he eats. The **blowfly** or bluebottle belongs to the latter class. The female lays her eggs in meat in batches of about a hundred, each egg being white, slender, and about one millimetre in length. No harm results if the meat be cooked before the eggs hatch. The larvæ, commonly known as "gentles", hatch from the eggs in about twenty-four hours, and are tiny, white, legless maggots, which feed on the juices of the meat. They moult several times, until at the end of five days each is fully grown, forms a cocoon from the larval skin, and becomes a pupa. Within three weeks from the time the egg was laid, a blowfly emerges from the cocoon. As blowflies lay their eggs in the flesh of any dead animals, the maggots may act as scavengers, helping to remove decaying animal matter.

The disease known as malaria is carried by a species of **mosquito** found in hot countries. To make blood flow, when the mosquito bites, it covers the skin of the victim with saliva which contains the **malaria parasites.** These enter the wound, and as soon as they reach the blood of the animal which has been bitten, each malaria animal, a one-celled creature, penetrates a red blood corpuscle. Within the corpuscle the malaria cell loses its elongated form, becoming amœboid, and grows until it fills the corpuscle, which thus becomes unable to do its work. The nucleus of the amœba-like creature then divides many times, and numerous daughter cells are formed. These break out and attack other corpuscles, and as cell division takes place very rapidly, the blood soon becomes filled with the parasites, which produce poisonous substances or toxins, and so the blood cannot function properly. The disease cannot spread to another man, however, except by means of the mosquito. When an infected man is bitten, the blood sucked up may contain cells of the malaria animal. Some of these cells may be special resting cells, each surrounded by a tough wall, so that when they pass into the digestive organs of the mosquito they are not dissolved. They then proceed to produce gametes, which fuse in pairs, and the nucleus of each resulting cell divides many times. Cytoplasm collects around each daughter nucleus, and many elongated, spindle-shaped cells are formed. These are set free and break through the wall of the digestive tube, eventually reaching the salivary glands of the mosquito, whence they pass into the wound of the next animal bitten by it. The malaria parasite thus passes its life history partly in the mosquito, and partly in another animal, and is, therefore, said to have two hosts. It causes disease, however, only in one of these hosts.

How can malaria be prevented? Like other mosquitoes, the one acting as host to the malaria parasite lays its eggs in water, where it also passes its larval and pupal stages. You may read in Chapter VI that these larvæ and pupæ must come to the surface of the water to breathe. In order, therefore, to prevent the spread of the disease, the insects are killed in their breeding places. If these be small ponds they are drained, but when they are too large to drain a thin layer of oil is poured on to them. Try to suggest why this means should be so effectual.

Another parasitic animal with two hosts, one of which may be man, is the **tape-worm.** As the name implies, the body is long and flattened, resembling a length of tape. There is

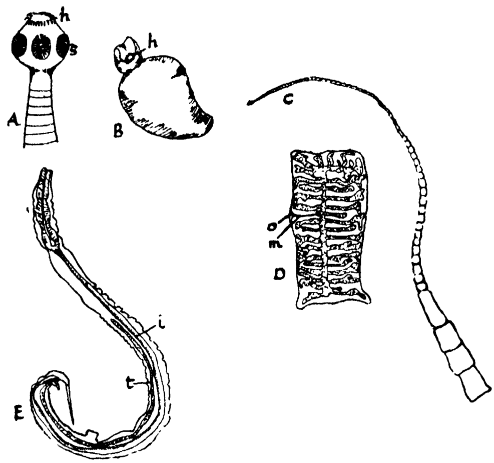


FIG. 59.

A. Head of Tape-worm } much magnified.
B. Larval stage of Tape-worm }
s, Sucker; *h*, Hooks.

C. Diagram of Tape-worm showing sections.

D. Mature section nearly filled by the much-branched uterus containing eggs. *o*, Opening of reproductive organs; *m*, Male duct through which spermatozoa escape.

E. Thread-worm—male (somewhat magnified). *i*, Intestine; *t*, Testis.

no digestive system, the animal being able to absorb through its entire surface the dissolved food material made by the host, who may thus be gradually starved. The body is divided into numerous white sections, narrow at the anterior end, but increasing in width towards the opposite end. At the anterior end is a head furnished with several suckers and hooked spines, by means of which it is fixed firmly to the internal wall of the intestine of the host. New sections grow from just behind the head, so that those at the posterior end are the oldest. Each mature section contains both male and female reproductive organs, and the spermatozoa produced fertilise the eggs in the same segments. As new sections are formed, the body grows longer and longer, sometimes reaching a length of several feet, and the oldest sections, containing fertilised eggs, break off and pass out of the animal in the waste excreted by the large intestine. The eggs cannot develop farther unless they reach the second host, which, in the case of the common tape-worm living in man, is the pig. When they reach the pig and pass into the digestive organs, their shells are dissolved by the digestive juices, and from each egg will emerge a little larva consisting of a ball of cells, furnished with six spikes. These tiny larvæ burrow through the wall of the intestine and get into the blood, which carries them to the muscles, where they break through into the tissue. Each then becomes surrounded by a tough, insoluble wall, inside which the tape-worm head, with its suckers and spines, develops. When the infected pig is killed and its flesh—spoken of as measly pork—eaten underdone, the young tape-worm passes into the intestine of man, where its strong enclosing wall is dissolved, and it fixes itself to the lining of the intestine, and proceeds to produce numerous sections. Once established here, it is very difficult to get rid of, so firmly is it fixed. The spread of tape-worms can be prevented by taking care that sanitary arrangements, especially in country places, are good, and that before pork is eaten it is well cooked. Other tape-worms may live in man and ox, sheep and sheep dog, dog and rabbit, dog and dog-flea. There is, however, one species that will live in dog and man, and as the eggs may get on to the fur round the animal's mouth, you should never allow dogs to lick your face or to feed from plates you may use.

Some species of round- or thread-worm may also live in the intestine of man and other animals, but as these worms are not fixed, they are much more easily removed. The round worm is small, slender, and white, with tapering ends, and lives usually in the small intestine of the host, where it absorbs digested food materials. When mature, each worm produces either eggs or spermatozoa, and the fertilised eggs may be shed in the intestine, where they proceed to develop, or they may escape to the exterior in the waste excreted by the host. These eggs cannot develop farther until they reach the intestine of the same kind of animal, so that it is only under exceptional or insanitary conditions that infection spreads.

Many diseases may be caused by uncleanliness, especially of external structures of the body such as nails, teeth, and skin. Dirt allowed to accumulate between the nails and the skin may contain disease-bearing organisms, which may be conveyed to the mouth by means of the food. The skin of mammals is made up of two layers, the inner being the dermis and the outer the epidermis (Gk. *epi*, upon; *derma*, skin). The epidermis is a thin layer, consisting on the outside of hard, horny cells, which are being continually worn away and replaced by cells underneath. When you take off dark coloured stockings you may see the shed skin as tiny white specks on the inside of the stocking. Continued pressure on the epidermis, such as may be caused by holding a tennis racket tightly for some length of time, or by wearing badly-fitting shoes, induces the formation of many more hard, horny cells, thereby forming "corns". The dermis is a thicker layer, and contains muscle fibres, fat cells, connective tissue and numerous blood capillaries and nerves. It is, therefore, the sensitive part of the skin, and the colour of the blood is seen through the transparent epidermis, giving the skin its pinkish tinge. Any other colours of the skin, such as black, brown, and yellow, are due to the colouring matter or pigment in the innermost cells of the epidermis. This pigment layer is thrown up into many curves, and the cells contain very little pigment in the European, and much more in the Negro.

With the help of a lens, look at the skin on the palm of your hand, and try to find the tiny pores, the openings of the ducts of small glands which secrete the fluid known as sweat or perspiration. The gland is a tightly coiled tube situated in the dermis, and is closely surrounded by capillary blood vessels and fat cells. Each duct is spirally coiled, and leads from the gland to the exterior of the body. The sweat secreted by the blood is composed mainly of water and mineral salts with a little carbon dioxide in solution. The skin thus acts as an excretory organ, and the quantity of sweat excreted by a human adult may be as much as two pounds per day.

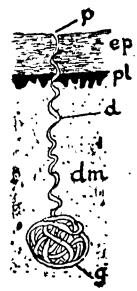


FIG. 60.—SECTION THROUGH HUMAN SKIN (much magnified).
ep, Epidermis.
dm, Dermis.
pl, Pigment layer.
p, Pore.
d, Duct of sweat gland.
g, Sweat gland.

Sweat is called a secretion, because it serves a useful purpose, helping to equalise the temperature of the body. Mammals are warm-blooded animals, and the temperature of the blood is kept fairly constant. Since heat is required to change water into vapour, the evaporation of sweat from the surface of the skin tends to reduce the temperature of the body. The greater the amount of sweat evaporated, therefore, the colder will be the body surface. In summer the surface may be exposed to great heat, and then the muscles of the skin relax so that the ducts of the glands open more widely, the blood supply is increased, and the sweat is given off freely. When you take exercise, extra energy is required and the muscles of your body receive an increased blood supply. You breathe more rapidly because more oxygen is required, and in the consequent oxidation of food materials to produce energy, much heat is set free, and a greater quantity of waste matter, especially of carbon dioxide, is excreted. The body temperature is increased by the heat produced, but the evaporation of much of the waste matter in the form of sweat tends to equalise the temperature again by cooling the surface. The amount of sweat is often so great that it can be seen clearly as beads of moisture on the skin. In cold weather, on the other hand, the amount is decreased by the action of muscles which reduce the size of the blood vessels surrounding the glands. At the same time the openings of the ducts of the sweat glands contract, so that less liquid can rise to the surface, and in this way the skin does not lose heat by undue evaporation.

From this you will readily understand how necessary it is to keep open the pores of the skin. Should they become blocked by dirt or by the solid matter left after the water has evaporated from the sweat, the waste matter which should be excreted from the glands may accumulate and cause various skin diseases. It is necessary to remove this solid matter by frequent washing in hot water; remember that the pores are situated over the whole body, and that all must be clean if they are to carry on their work properly.

The hairs found as outgrowths of the skin in mammals are formed by both dermis and epidermis. Each hair fits into a pocket sunk in the dermis, but lined with a continuation of the epidermis, and the base of the hair, filling the pocket, is the root or bulb. The rest of the hair, forming the shaft, is a tube, and as the growing point is at the very base of the hair, continual additions to this region push forward the tube. The root is supplied with blood vessels and nerves, but the shaft has no blood nor nervous supply: hence you do not feel pain when your hair is cut, but only when it is pulled out by the roots. There are tiny glands around each hair, and these secrete an oily fluid, which prevents the hair from becoming too dry. The fluid may pass up the pocket into which the hair fits, and so accumulate on the scalp, whence it can be removed by washing with hot water. Around each root there are also muscle fibres, which, when they contract, pull the hairs into a vertical position, and so make the hair "stand on end".

Some diseases may be avoided by due attention being paid to the care of the teeth. In Chapter IV the teeth of the cat are described. The teeth of all mammals fit into bony sockets in the jaw, and are composed of the same kinds of substances as those composing cats' teeth. Between them, just above the gum, are spaces, which, during feeding, may become filled with particles of food. In those animals which eat hard food, there is less likelihood of food collecting here, but in others, unless the accumulated food particles are removed, they become stale, and on them numerous bacteria live, and in feeding produce poisonous substances which may eventually be swallowed, and so cause disease of the digestive organs. The bacteria may also produce acid substances which have the power of dissolving the enamel covering the teeth, and so cause them to decay. We do not find that the teeth of animals feeding on hard substances decay easily, so you may help to prevent decay of your teeth by chewing apples, crusts, and other hard foods. As human beings do not eat enough hard food to keep the teeth healthy, it is also necessary to brush your teeth thoroughly after meals to remove surplus food, and so prevent disease.

Plant Diseases

Both plants and animals are subject to diseases, many of which can be prevented by foreknowledge. It is nearly two hundred years since an Act of Parliament was passed in America to the effect that all barberry bushes growing near cornfields should be pulled up and burnt. This may appear to you to be strange, and if all farmers in our country to-day were ordered to destroy certain bushes growing in the hedgerows around cornfields they would demand to know the reason for the order. There certainly was good reason for the Act of 1755, since it had been found that wherever wheat was diseased in a certain way, there were always barberry bushes growing near. It was not, however, till nearly forty years afterwards that the connection between barberry and the wheat disease known as **rust** was discovered. If you look at the lower surface of barberry leaves in spring, you may see many bright orange or rust-coloured patches of powdery-looking substance. These patches contain masses of fungus spores, which are set free by the wind in early summer, and may fall on young corn plants, such as wheat, oats, and rye. The leaves and stems of these plants are covered with a very tough outer skin or cuticle, incapable of being penetrated by the spores, so when these reach the leaves, each produces a tiny outgrowth which grows longer until it reaches a stoma. It then grows in through the opening and so penetrates the tissues of the new host. Here the fungus grows, spreads throughout the spaces between the cells, and sends tiny projections into them to absorb the food made by the host plant, which thereby becomes starved and unhealthy. Towards the end of summer, dark-coloured—almost black—patches may be seen on the corn attacked by the fungus. These contain dark brown resting spores, and when the host plant dies down they rest until the spring, when they can grow only if they have reached the other host plant, in this case the barberry. On the barberry leaves the spores send out tubes which are able to enter through the cuticle, and, once inside, they grow and spread through the leaf tissues as in the wheat. In a short time the rust-coloured spores are produced in patches or "cluster-cups" on the lower surface of the leaves, ready to carry the infection to new wheat plants.

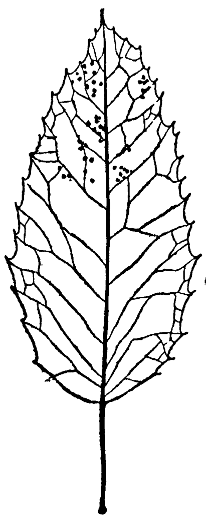


FIG. 61.—LOWER SURFACE OF BARBERRY LEAF SHOWING "CLUSTER CUPS" OF RUST.

Plant "rust" is thus caused by a fungus which, like the tape-worm, needs two hosts in order to complete its life history, and when one of these hosts is not available, the disease cannot spread.

A common disease of potatoes is known as **wart disease.** This is caused by a fungus living as a parasite in the tubers and sometimes in the aerial stems of the potato plant. In growing, it causes swellings and eruptions of the skin, forming warts, which at first appear as little white patches, but these increase in size and become black, until finally the whole leaf or tuber becomes a dark, putrid mass. The resting spores produced by the fungus can live in the soil for many years, and are not killed by dressing it with lime or other chemical substances. In order to prevent the disease, it is not only necessary to burn all infected plants, but also to plant in infected soil either different kinds of crops or special varieties of potato known to be disease proof. As the resting spores will grow also on plants of woody and deadly nightshade, and

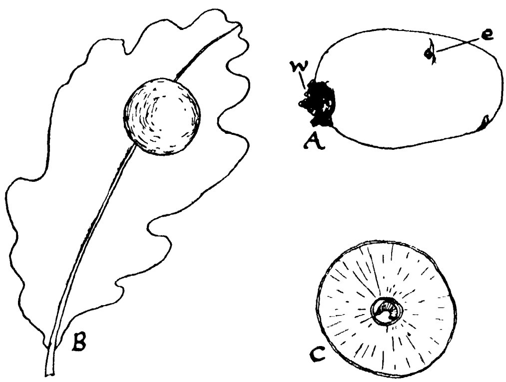


FIG. 62.

A. Potato tuber attacked by wart disease. *w*, Warts; *e*, Eyc. × ½.
B. Marble gall on oak leaf. × ½.
C. Gall cut open to show larva inside. × 1.

in them produce more spores, these weeds should always be destroyed by burning.

You may find on oak-trees, rose-bushes, and other plants, large or small, more or less spherical protuberances, spoken of as **galls**. These are unhealthy swellings caused by insects, mostly by gall wasps, the females of which pierce the epidermis of the plant and lay their eggs just beneath the skin. The larvæ which hatch from the eggs are maggot-like creatures with strong jaws by means of which they pierce the plant tissues. Some of the plant cells immediately surrounding the larvæ divide repeatedly and build up layers of tissue to enclose them, thus forming a gall. The outermost layer of the gall is composed of the epidermis of the plant, while the innermost is that from which the larva draws its food. Between these two is a spongy layer, clearly seen in the oak apple gall, while, as in the marble gall, there may often be a hard protective layer as well. After the larvæ have become pupæ, and the flies are ready to emerge, they bite their way through the tissues of the gall and escape. The female gall wasp which emerges from the oak apple gall is wingless, and lays her eggs in the roots of the tree, where other galls are produced. From these, in spring, emerge winged females only. These migrate up the tree and lay unfertilised eggs, from which are hatched larvæ causing the formation of oak apple galls. This insect, therefore, shows an alternation of generations, one generation being composed of winged males and wingless females, which lay fertilised eggs, giving rise eventually only to winged females. These in their turn lay unfertilised eggs, from which in due time winged males or wingless females are produced.

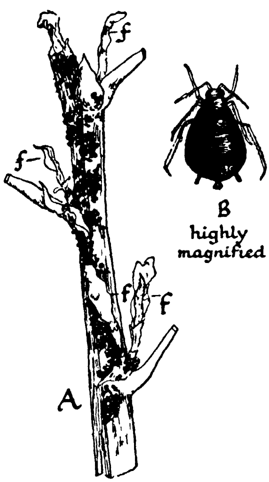


FIG. 63.
A. Part of broad bean plant attacked by Black Aphis. *f*, Shrivelled flowers.
B. Black Aphis—wingless female.

Aphides, some of which are known as green-fly, are often responsible for diseased plants, since most of them feed on the sap of young shoots and foliage leaves. The black aphis lives on the growing tips of shoots of the broad bean. The young plant is attacked in spring by winged females, in which eggs develop, and are hatched into wingless females and occasionally a few winged females. These are born in spring and early summer and migrate to other plants. As the young are produced in rapid succession, the tips of growing plants become encrusted with the black flies, and soon shrivel up and die. When food is getting scarce, winged males and winged females are produced; these pair and the fertilised eggs laid by the female remain undeveloped in sheltered places until the following spring, when they give rise to the females which attack the bean plant. It is practically impossible to prevent attack by this insect pest, but attacks can be controlled by removing young growing points as soon as the flies are seen. The fly may be killed by spraying with various oily or soapy solutions.

PRACTICAL WORK

1. Cut a grain of wheat longitudinally and make a drawing to show the different parts.

2. Use the tests suggested at the end of Chapter X to find out whether the grain contains starch and protein.

3. Place a small quantity of flour in a muslin bag and knead well with water. Evaporate some of the whitened water and test the residue with iodine. Test the residue left in the bag with Millon's reagent. Account for your results.

4. Put some peas and beans in fireproof dishes and heat strongly until only ash remains. This ash represents the mineral matter in the plant.

5. Take equal weights of various food-stuffs and do an experiment to compare the amounts of mineral matter they contain.

6. Buy a few tubes of sterilised agar jelly from the chemist. This jelly is made from certain seaweeds, and bacteria will grow on it. Place the tubes in a vessel of water, and heat it to boiling-point. Keep the tubes in the boiling water till the agar jelly melts. Then take them out and rest them in a slanting position till the jelly is nearly set. Use them for experiments 7 to 11.

7. Take out the cotton wool plugging the mouth, leave the tube exposed to the air for ten minutes and replace the stopper.

8. Repeat experiment 7, but add two or three drops of a disinfectant before replacing the plug.

9. Add a little saliva from the mouth.

10. Add small pieces of wallpaper.

11. Add a piece of dress material.

12. Label each tube clearly and place it in the dark for a week. At the end of that time look for groups of bacteria (which appear as white

or yellow, red or black patches) and compare the number and size of the patches in different tubes. Suggest an explanation of your results.

13. Repeat experiment 12, using three tubes, and in one place a drop of fresh milk, in a second, boiled milk, and in a third sour milk. Account for your results.

14. In each of two vessels pour equal quantities of fresh and boiled milk. Leave each in a cool, dark place for a week. Try to explain your results.

15. Make up an experiment to find the effect of light and of darkness on the growth of bacteria.

16. Devise an experiment to find whether heat and cold affect the growth of bacteria.

17. Make up experiments to find whether brine and vinegar are useful in the preservation of food.

18. Keep green-fly on their food plants in insect cages, and watch their development. Keep a record of the dates when any changes in the life history occur.

EXERCISES AND QUESTIONS

1. Discuss the need for a mixed diet.

2. Name the plants and the parts of plants in which large quantities of protein and of starch are stored.

3. What are bacteria? How do they differ from ordinary plant or animal cells?

4. Describe any disease caused in man by bacteria.

5. Suggest ways in which bacteria are useful to man.

6. Name any parasite which lives in two hosts. Describe the life history of the parasite.

7. In what way may dogs and cats spread diseases in man?

8. Describe the life history of the malaria parasite.

9. How can the spread of malaria be prevented?

10. Mention any reasons for decay in teeth, and say how decay may be prevented.

11. Describe the structure of the skin in mammals.

12. Why is the skin an organ of excretion? Compare the substances excreted with those excreted by lungs and kidneys.

13. Discuss the effect of the temperature on the amount of sweat excreted by the skin.

14. How do warm-blooded animals maintain their high temperature during cold weather?

15. Why should barberry not be allowed to grow near cornfields?

16. What do we mean by "rust" in wheat? Say what you can about it.

17. Mould is a plant. Is this statement true? Give reasons for your answer.

18. Write out the life history of an insect which shows an alternation of generations.

19. Mention any ways in which the spread of the black aphis can be prevented.

CHAPTER X

HOW ANIMALS AND PLANTS STORE FOOD

If you were to go without food for a day you would probably feel faint and uncomfortable, but it is unlikely that there would be any more serious consequences. Since, however, you would continue to breathe, the oxygen must be joining with some food material to produce the carbon dioxide you expire, the heat to keep your temperature normal, and any other energy you may be using. How is this food material obtained? It may be that your last meal provided food sufficient to last a whole day, but this is unlikely. People have sometimes had to fast for several days, and it is certain that their last meal could not have sufficed so long a time. At the end of such a period of fasting people are thinner and have lost weight, for they have been living partly on the actual material composing some of the cells of the body, and partly on the food stored in other cells.

What is this food store, and how does it arise? Although human beings do not eat with the intention of hoarding supplies of food within their bodies, most of them eat more than will supply their daily needs, and the excess food is stored in various cells. Surplus fat is stored in cells beneath the skin and in any internal furrows. Excess of sugar is converted into an insoluble substance which is stored in the cells of the liver. These cells produce an enzyme which effects the change of this substance into sugar when it is needed. The nitrogenous foods, or proteids, have increased the substance of the muscle cells, and this is partly consumed, together with the fat and other stored food, when the body needs them.

Why should any food be stored? A store is a provision for a time of need, and our internal food stores enable us to live through periods of enforced shortage of food, should they occur. In the life of primitive man they probably occurred frequently, when the hunting was not good.

Several other animals have to endure very long periods when they are unable to procure food. British snakes feed on worms and frogs, but in the winter the worms burrow more deeply into the soil and the frogs also burrow, so that the snakes can get little food. The snake then hides in a sheltered place and sleeps until the spring, when the worms and frogs emerge from their winter rest or hibernation. At the beginning of winter the snake has two bright yellow fat-bodies within it; in the spring these bodies have almost or quite disappeared.

Frogs can get no insects or worms in the cold weather, and, like the snake, the frog uses the food from its two fat-bodies while it hibernates.

The dormouse and the hedgehog also lay up stores of fat when food is plentiful, and then in the winter sleep very soundly in their nests, not waking to feed until the following spring.

Most animals living in cold places store more fat than others. The sperm-whale may store a ton of oil in its skull in a cavity lying just above the brain case.

Large quantities of oil and other fat are also produced by the walrus, seals, and sea-elephants, so that they can survive when their food is frozen in the ice, or has migrated to a warmer place.

Frequently man kills these animals to obtain their winter food stores. He uses the oil obtained from the porpoise to lubricate delicate machinery. The Esquimaux burn the oil stored by the seal and use the fat or *blubber* of the animal as food. The sperm-whale and walrus are also hunted extensively for their large supplies of oil.

In the desert the camel may have to continue for some time without food or water. The humps of the camel and dromedary consist mainly of stored fat, which is gradually made soluble and used as it is required. When the camel eats juicy desert plants like the cactus, which stores up water, and when it drinks, the excess of water passes into the paunch, a special chamber of the stomach, and is there stored in hundreds of tiny flask-shaped reservoirs which line the walls. Each reservoir, when full, is closed by a ring of muscle cells round its margin, and these, by relaxing, allow the water to trickle out from each reservoir as it is required. When the camel has plenty to eat, but not enough to drink, the internal water supply is used, but the fat in the hump remains unused, or may even be increased.

Some fishes hibernate by burrowing in the mud. In our climate the carp does this in the cold weather; in Australia, where the rivers dry up in the hot season, the lung-fishes and the mud-fishes coil themselves in the mud and sleep until water returns. Many fishes store oil: you may see drops of it ooze from a herring or mackerel put in a dish in the oven, or before the fire, and the bottles of cod-liver oil you may see in any chemist's shop will remind you that the cod also stores oil. Crabs, lobsters, and other Crustaceans are other oil-producers, and although their supplies are too small to be considered by man, he uses them indirectly because the sperm-whale feeds on large numbers of minute Crustacea which, in proportion to their size, contain large quantities of oil.

Female animals need food reserves for an additional reason. You may read how the frog and the trout lay eggs containing food sufficient for the young animals to grow large enough to secure food for themselves.[1] This supply in the egg was drawn from the food store of the mother, and all animals producing eggs which contain food provide it from the mother's reserves. This is the chief reason why salmon and other fish are not caught at the end of the breeding season. Much energy is used in laying the eggs, which receive most, if not all, of the food supply of the female, so that she is flabby and completely exhausted after they are laid. The food reserve of

[1] Chapter VII, pp. 137, 143.

the male is used to produce the millions of spermatozoa. So many of these are lost when they are liberated in the water that if they were not produced in such enormous numbers comparatively few of the eggs would be fertilised. Very many animals use their food reserves in a similar way during the breeding season, when special storage structures, such as fat-bodies, may completely disappear.

In plants, too, food is stored for the same reasons as in animals. The oil in Spirogyra and the starch grains in Chlamydomonas help the plants to survive unfavourable periods, and to continue their growth when good conditions return.

The carrot, parsnip, and beetroot store sugar, and all use their tap-roots as storage organs. If you grow any of these plants, you will find that, unless they are in extremely poor soil, they will produce no flowers until the second year of their growth. Their first year is spent in building up and storing food until enough is saved to produce the flowers and seeds. Such plants are described as **biennials.** Some of them, like the celery and rhubarb, store food in their leaf stalks.

If you grow the sweet pea or the poppy, you will find that in favourable conditions the plant produces seeds and flowers during its first year and then dies. If you want plants to grow during the following year you must collect the seeds and plant them at the best time. Plants which in this way complete their whole life history in a year are called **annuals.**

Other plants in your garden will grow year after year: these are the **perennials.** Some of them have to store food for several years before they have enough to produce flowers and seeds, but once they have saved enough to start, they may continue to flower every year. All our British fruit-trees are perennial, and most of them have no food to spare for flowering until they have grown for at least five years.

The century plant, or *Agave*, stores food in its swollen leaves year after year, for any period from five to a hundred years, according to the conditions under which it is growing. In Mexico, usually after from five to eight years, the plant produces many flowers, forming an inflorescence which may be twenty feet high. All the plant's energy and food is used in producing this enormous mass of flowers and seeds, and it dies after they are shed. The leaves become so juicy while storing the food that thirsty Mexicans often "tap" them and drink the sap. When grown in hothouses in England the *Agave* usually takes forty years or more to save enough food for flowering.

The stonecrop is a British plant which grows in dry places and stores water in its leaves, making them succulent. You may find this plant in niches in old walls and between the tiles of roofs.

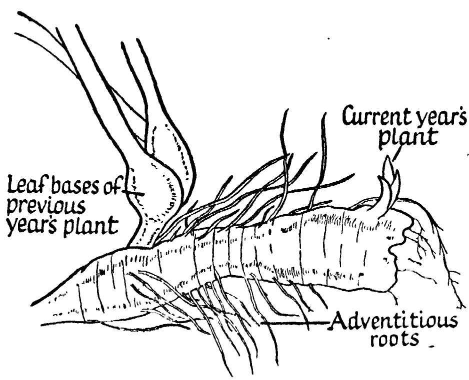


FIG. 64.—RHIZOME OF IRIS. × ⅓.

If you can keep a cactus for some time, you will find that on the fleshy green part similar fleshy structures may arise as branches. This part must therefore be a stem, and eventually, if conditions be favourable, flowers will grow from it. The leaves are reduced to small hairs, which may be very spiny in some species of cactus—the prickly pear, for example. The cactus grows naturally in dry places, and whenever it can get water stores it in its stems, making them fleshy. In Chapter XIII you will find experiments which will enable you to show that leaves give off water, so the store of the cactus is preserved by their reduction, while the large green stem is able to build up the food and do the other work of the leaves.

Some perennials store food in special underground stems, such as the rhizomes of ferns, the iris, and montbretia. The potato stores large quantities of starch in its tubers. Examine

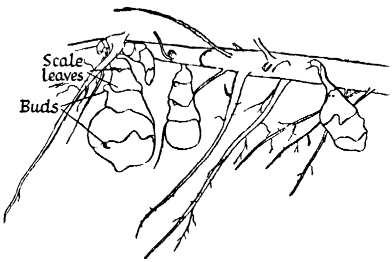


FIG. 65.—JERUSALEM ARTICHOKES $\times \frac{1}{4}$ (stem tubers).

a potato and notice the " eyes". Leave the potato in a dark, moist, warm place, and you will find roots growing just beneath the "eyes" which are sprouting. The potato then must be a stem, since it bears buds. Such swollen underground stems are tubers, and every year, if conditions be favourable, the buds on each tuber grow into new plants, which in their turn produce other tubers. The Jerusalem artichoke grows in a very similar way to the potato.

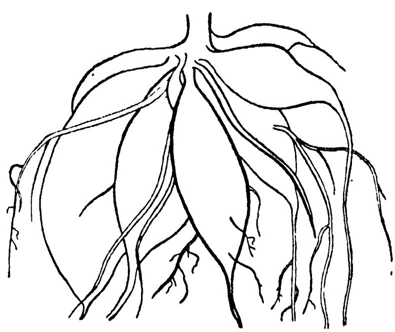


FIG. 66.—ROOT TUBERS OF DAHLIA. $\times \frac{1}{4}$.

Examine the roots of a Dahlia or of an orchid. They are fibrous, and some of the fibres may have had so much food stored in them that they have become tubers. On these, however, you will find no "eyes" as on the potato, but at the top of each is a bud produced from the stem. The tubers of the Dahlia and orchid are root-tubers, and during the following year the bud grows into the new shoot, which builds up food and sends it down into the new roots to form other tubers.

Most of our British spring flowers are perennials, and their food stores enable them to grow in weather which is too cold for most flowering plants. Dig up a primrose, a violet, and a cowslip, and notice the short rhizomes which grow almost vertically through the soil and are spoken of as "root-stocks". The herb Paris and the moschatel, a small plant with delicate green leaves and green flowers massed together to form a spherical head, have creeping rhizomes. Daffodils, tulips, and bluebells have bulbs, the crocus has a corm, and these structures, which are described in the next chapter, contain large food supplies.

Structures very similar to bulbs, and described as bulbils, are produced by some lilies which pass their excess food into buds. Leaves of these become fleshy and the buds form small green rosettes, which drop off and grow into new plants.

Since young land plants, unlike most young animals, are unable to move about to secure food, it is essential that they should start life with enough food to enable them to become strong enough to start work for themselves. The parent plant is unable to sow its seeds in favourable situations, so most plants either produce a very large number of small seeds, or else fewer seeds each with a large food supply. If the seeds be small and numerous, although many may be wasted, there is the probability that at least some will be blown to favourable surroundings and will grow successfully. If the seed be well supplied with food, the embryo will have enough to enable it to grow into a strong plant before beginning to compete with the plants around it for food and air. Nuts have stores of oil and proteids, cereals have densely packed supplies of starch, peas, beans, and lentils contain large quantities of proteids, and grape and date seeds have a hard stony substance called cellulose. All these food stores in the seed have been supplied by the parent plant's food reserve.

If you know that a time of food scarcity is coming, you do not consume larger meals, but you lay up a store of provisions and use them as you need them. On account of their structure and mode of life, plants are unable to provide external food stores, but many animals are able to hoard food either to save themselves the trouble of hunting for it every time they need it, or to help them through a time of scarcity.

The squirrels and field mice sleep through a great part of the winter, but wake at intervals and feed on the stores they have collected during the summer and autumn. The squirrel stores nuts, usually in a convenient hollow in a tree, in niches between the branches, or under leaves and loose soil. The mice collect grass seeds, grain, acorns, and nuts. After feeding, the animals sleep again for some time.

Grain is collected also by the harvest-ants of India and the warmer countries of Southern Europe. This habit of the ants was recognised centuries ago and recorded in the Bible, in the book of Proverbs. Some of these ants lay up such large stores that disputes have arisen between the gleaners and the owner of the land, the gleaners claiming the right to remove the ant's heap of corn, while the land-owner considered it as his property. Some kinds of Indian ants store enough grass seeds to last them from February to October. If these seeds were left lying on the soil or buried beneath it, under the usual conditions, they would germinate. How does the ant prevent the seeds from growing into new plants? In some cases it was found that the seeds began to germinate, but the ants gnawed off the radicle and so prevented germination from proceeding farther. It is quite possible that the ant allows germination to proceed to a certain stage so that the starch stored in the grain may be converted into sugar, on which the ant feeds.

Other ants found in hot countries are known as agricultural ants, because they cultivate a large area of ground, often as much as a hundred square feet. These ants feed on rice, and they remove any other plant from their area, so that by careful weeding they have established small rice plantations around their homes.

The leaf-cutting ants of South America bite from leaves circular areas about the size of a sixpence, and store them in their burrows. A certain kind of fungus grows on the leaves as they decompose, and on this fungus the ants feed.

None of our British ants store food or grow their own food as these ants in tropical countries do, but if you cautiously disturb an ant-hill in late autumn you may watch the ants hurrying away with white larvæ and with eggs of different kinds. Some of these eggs are those of the green-fly, or its near relatives. We try to remove these insects, the aphides, from our gardens because they feed on the juices of plants. The ant, however, takes as much care of the eggs of the *Aphis* as of its own, and when the *Aphis* larvæ are hatched in spring and try to struggle out from the soil, the ants will even carry them out and put them on the plant they need for food. In the summer, if you look, you will probably find many fully developed aphides in the ants' burrows. Why should the ant take such care of the aphides? You may be fortunate enough to find an ant stroking and tapping an *Aphis* with its antennæ. These caresses induce the insect to secrete a sugary liquid from its abdomen, and on this the ant feeds. The ant is "milking" the *Aphis*, and guards it as we guard our cows.

The bee is famous on account of its hoards of honey. From early spring to late autumn the workers collect nectar from the flowers and store it in the cells so that the bee colony shall have enough food during the winter. In good seasons the bees usually store far more than will meet their needs, so man relieves them of their surplus store. In fact, some bee-keepers take most of the honey and feed the bees on sugar during the cold season, but this is not so good for the insects, and it is generally considered best to leave them enough of their own hoard.

The mole has a pantry in which it confines living victims. If a worm be beheaded, it remains alive, and within a few days grows a new head. The mole collects worms in its burrow and bites off their heads, and the victims cannot escape because they need their heads to burrow through the soil. Before the new head has fully developed the worm is eaten.

The butcher-bird, or shrike, catches smaller birds and strings them on the spines of sloe-trees or hawthorns, in much the same way as the butcher passes a skewer through meat. The victims are then more or less quickly devoured, according to the appetite of the captor.

Some animals which neither store much food for themselves nor for their eggs are careful to put their eggs in places where food is at hand for the larva directly it develops. The blow-fly lays her eggs on meat; the cabbage butterfly deposits her eggs on the leaves of cabbages; the mason-wasp, described by Fabre, makes a mud nest, puts a small spider in it, and then lays her egg. She now fills the nest with small spiders which she has killed, and closes it with a layer of mud. When the larva develops it eats the first, and stalest, spider, and gradually feeds on the others until it reaches the top one, which was the last added.

Other wasps paralyse caterpillars and lay their eggs in the bodies of these insects, so that the hapless creatures remain alive as a source of fresh food for the larvæ.

The ichneumon-fly also chooses the unfortunate caterpillar as a meat supply for its larvæ. The eggs, laid in the caterpillar, develop into larvæ, which eat the flesh of the insect without injuring any of its vital parts until it pupates. The flies inside also become pupæ and emerge later from the dead chrysalis.

These are only a very few of the examples of insects which deposit their eggs on a food store. You will probably be able to find many others if you hunt for them in your garden and in fields and woods.

PRACTICAL WORK

Examine the following plants, and make drawings showing the parts in which the food is stored:—

1. Carrot.	4. Beetroot.	7. Potato.	10. Onion.
2. Radish.	5. Dahlia.	8. Iris.	11. Crocus.
3. Parsnip.	6. Primrose.	9. Cactus.	12. Stonecrop.

13. Compare and contrast your drawings of the potato and Dahlia tubers and say from what part of each plant the tubers are formed.

14. Look at your drawing of the radish and of the Dahlia tuber and account for the differences in structure.

15. Compare the rhizome of the iris with the shoot of a rose-tree. Make a list of the ways in which the two resemble each other, and a list of their differences.

16. Crush a brazil-nut between the folds of a piece of clean blotting-paper. Notice the stains and try to remove some with water and the others with xylol or with petrol. What is the stain?

17. By adding a few drops of iodine, test the cut surface of each of the following for starch: Broad bean, acorn, horse-chestnut, pea, apple, root stock of primrose, rhizomes of bracken and iris, rhubarb stem, potato, Dahlia tuber, carrot, turnip. Make lists of all those containing starch, noting whether much or little be present, and of those containing no starch.

18. Cut a moderately thin slice from each of the plant parts mentioned in the previous exercise, lay it on a glass slide and add to the cut surface a drop of Millon's reagent (a solution of mercuric nitiate acidified with nitric acid). Warm the slide. If a pink precipitate be formed, proteid is present. Make lists of all those containing proteid and those which do not.

EXERCISES AND QUESTIONS

1. What is a biennial? At what period of its life would you expect to find the greatest amount of food stored in it? Give your reasons.

2. Name three animals which have "fat-bodies" within them. What is the use of these bodies?

3. Name six animals which collect external food stores. Say in each case what the food is and how it is stored.

4. Many insects lay eggs containing very little food supply for the larva. Why are these insects so plentiful?

5. Give six examples of seeds containing large food stores. Why should the store be large?

6. Why is it that each year an iris grows up in a different place, while an apple-tree does not?

7. Make a list of all the resemblances between a potato and the rhizome of an iris or of a fern.

CHAPTER XI

HOW TO GROW PLANTS FOR DECORATION

THE best plants to grow indoors are hyacinths, crocuses, daffodils, tulips, snowdrops, and the narcissus. Most of these plants grow from bulbs similar to that of the bluebell, described in Chapter V, but the crocuses grow from corms.

Examine an onion and a crocus. Notice the brown scale leaves and the flat disc of each, and observe any differences

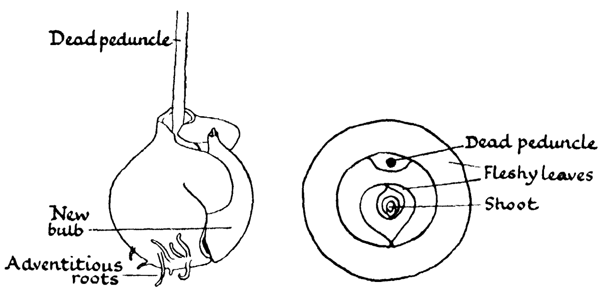


FIG. 67.—BULB OF BLUEBELL. × ½
Transverse section. × 1.

between the discs. Carefully remove the scale leaves and look for outgrowths from the surface they disclose. Cut the bulb and the corm longitudinally through the centre. Here you will discover the greatest difference. Whereas the onion consists of many overlapping fleshy leaves enclosing the young plant in the centre, and perhaps having at their bases some tiny buds on the short conical stem, the corm is a solid mass having the young plant as a bud at its apex. At the base of the corm may often be found the shrivelled remains of the previous year's corm, and sometimes other small buds grow out from the surface beneath the scale leaves. Thus the corm is an enlarged stem stored with food and bearing an apical bud which will form the new shoot. Sometimes it also bears lateral buds which may develop into shoots.

When your bulbs and corms have flowered and the leaves are dying, examine a hyacinth bulb, a narcissus or snowdrop bulb, and a crocus corm. Like the bluebell and onion, the hyacinth will have produced one or more new bulbs by passing food stores into the tiny buds on the axis between the fleshy leaves, which now are shrivelled and will form the scale leaves of the new bulb. The narcissus, however, produces its bulbs in a different way. The bases of the green leaves have become swollen and form the fleshy "leaves" of the new bulb. In the centre is a bud with delicate leaves, which will grow into the foliage leaves in the following year. The scales are formed by the shrunken fleshy leaves, which have sent their food store to be used for the growth of the plant which has just died.

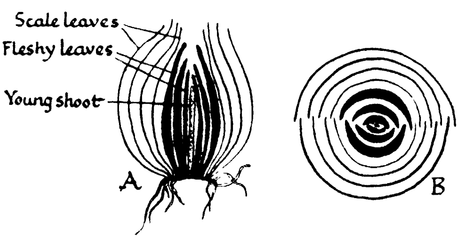


FIG. 68.—BULB OF SNOWDROP. × 1½.
A. Median longitudinal section.
B. Transverse section. × 2.

Take another narcissus or snowdrop bulb, and one of the hyacinth or onion, and peel off the fleshy leaves one by one: you will find that those of the narcissus only just overlap, while those of the onion wrap round the bulb. If you noticed how the green leaves of the narcissus only just overlap at their bases, while the outer leaves of the onion bud are wrapped almost completely round the inner ones, you will understand the difference in the arrangement of the fleshy leaves of the two bulbs.

Now examine the crocus corm. It seems to be built of three storeys, the lowest being the very small shrivelled remains which you observed before. The middle storey is very soft and shrunken, and the top storey consists of a rounded, firm, white body, which is the new corm. The dead leaves of the plant have withered at their bases and form the protective brown scales. The corm you planted has sent its food into the growing bud and produced the shoot. The green leaves have made food and sent it down to the base of the stem, where it has been stored as starch, and the tiny new bud at the top will grow into next year's plant. So the corm adds successive storeys year by year, but the lowest ones become so shrivelled that usually they are impossible to distinguish separately.

You may grow your bulbs and corms in fibre, in soil, or in water, but fibre is the most suitable, and you can get enough from the florist or seedsman for a few pence. Use bowls which are from one and a half times to twice the depth of the bulbs you are planting. Soak the fibre in water and squeeze it until no more water drops out. Then spread a layer at the bottom of the bowl with a few small pieces of charcoal, and place the bulbs about an inch apart. Pack the fibre round them until they are just covered. See that the fibre is firmly packed, but is not hard and lumpy. Put the bowls in a dark cellar or cupboard, where they have plenty of air but are free from draught. If they are in a warm, dry place, remove them once a week and stand them in a large bowl or sink filled with water, and when no more bubbles rise to the surface remove the bowl of bulbs, press the fibre down with the hand, and drain off as much water as possible before replacing the bowl in darkness. If the bulbs are in a damp cellar they will need less frequent watering. Keep them in the dark until all the

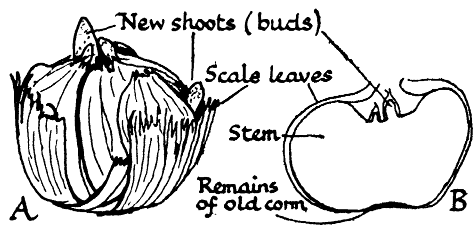


FIG. 69.
A. Corm of Crocus. × 1½.
B. Longitudinal section. × 1½.

shoots are showing well. This usually takes from three to six weeks, but the time depends partly on the nature of the bulb, and partly on the temperature. Then remove the bowls to the place where you wish to keep them. See that the plants are not too near the fire nor in a draught, and that the fibre is kept moist. A light place near the window or on the window-sill is best, but you must remember to turn the bowl round every day, otherwise the plants will grow one-sided.

When flowering is over, cut off the dead flowers and continue to look after your plants until the leaves have completely withered. Then cut them off, take out the bulbs and separate any new ones that have grown within the same old one. Store them in the cellar or in a greenhouse under a heap of ashes, and replant them from September to December. Those planted earliest are most likely to flower first.

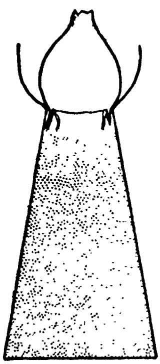


FIG. 70.—BULB GROWING WITH ROOTS IN WATER.

If you use soil instead of fibre you must mix it with charcoal to make it more porous, and you must use flower-pots or bowls provided with holes for drainage. Treat the bulbs in the same way as those in fibre: growth will probably be slower.

To grow bulbs in water, get a bottle with a neck just wide enough for the bulb to rest in it. Nearly fill the bottle with water and keep the water-level from a quarter to half an inch below the bulb, and then treat it in the same way as described for bulbs planted in fibre. If required, special glasses may be bought for growing bulbs in water.

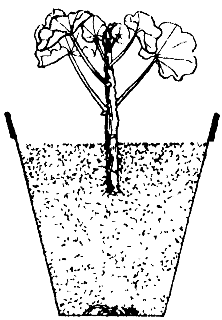
There are many ways of growing plants for decoration other than from bulbs or corms. Seeds, for example, may be sown in pots or in window-boxes. Flower-pots used for this purpose should first be well scrubbed inside and out, and left out of doors to drain until quite dry. Seeds or plants should never be set in damp pots. In the bottom of the pot loosely pack some pieces of broken pot or a few stones to cover the hole, but at the same time to allow for drainage. Cover these with decaying leaves or a little moss, then fill up with soil to within one inch of the top. The best kind of soil to use is a mixture of three parts loam, one part sand, and one part leaf-mould. Loam is a mixture of sand and clay, and the best way to obtain it for potting purposes is to dig a few sods or turves from any grassy place and pile them in a heap, grass side downwards. They should be left like this for as long a time as possible, at least for several months, so, for loam required in spring, prepare the turves in the previous summer or autumn. When well decayed, they may be broken up and mixed in the correct proportion with leaf-mould, which is prepared from leaves collected in the autumn and left to decay throughout the winter. Sand may be obtained from nurserymen.

Suitable plants to grow from seed are asters, wallflowers, antirrhinums, lobelias, mignonette, marigolds, nasturtiums, petunias, stocks, and forget-me-nots. The seeds should be lightly scattered and a thin layer of soil pressed down over them. Always keep the soil surface below the rim of the flower-pot, and place the pots in a warm place, not too near the light, till the seedlings show above the surface of the soil. When the soil becomes dry, place the pots in water, so that it rises about half way up their outer surfaces, and remove them when the surface soil has become moist. For plants grown indoors, tepid rain-water should be used for this purpose. You can tell when the soil is dry by tapping the outside of the pot with the knuckles; a clear, hollow sound is produced. When the young seedlings are about an inch high, gently pull out a few to thin them, so that those left have sufficient space for growth. Keep the soil moist, and put the pots in a place where they are warm, receive plenty of light, and get air without being in a draught.

The same kinds of plants will also grow well in window-boxes. You can make a window-box by nailing together planks of wood six to nine inches wide and nearly as long as the window-sill on which it is to be placed. Drill holes in the bottom of the box, and nail on to the outside small strips of wood to lift it above the surface of the window-sill, and so allow for drainage. Paint the box, and when it is quite dry place crocks or stones in the bottom and fill with the same kind of soil as that used in pots. As the boxes are larger than pots, several kinds of flowers may be grown in each. Plant the shorter ones in front and the taller ones behind. You may like to choose a colour scheme, such as yellow, red, and brown, in which case you will set in the box only plants which produce flowers of those colours. The seeds should not be sown directly in the boxes, but in pots indoors, and the young plants transplanted when a few weeks old. Before transplanting, see that the soil in the boxes is moist, and make small holes in the surface in the places where you wish the plants to grow. Plants with the same coloured flowers often look better grouped together than dotted about singly here and there. Lift each seedling gently from the pot, scraping out with your fingers a quantity of soil around its roots. Transfer soil and plant to its new quarters, and press down the soil firmly with the fingers. The seedlings may wilt at first, but will regain their freshness when firmly rooted. If the box be in a very sheltered place, water the soil occasionally and loosen it around the plants with a small hand-fork.

Another method of growing plants for decoration is by means of cuttings. By this method you may grow your pelargoniums, fuchsias, calceolarias, and violas. The pot or box is prepared beforehand as for seeds, but the soil must contain more sand. Cuttings are made usually in autumn, and each consists of a young shoot cut with a sharp knife from the parent plant just below a node. The cutting is left for about a quarter of an hour, so that the wound may become dry before planting. The end is embedded in sandy soil so that the shoot is covered up to about an inch and a half to two inches above the cut. A layer spoken of as a callus forms on the cut surface, and beneath it are special cells which divide, producing new roots. Cuttings of pinks are made by pulling off a shoot at a node, and inserting it at once in sandy soil and keeping it in a warm place. A special method of producing new plants, such as carnations, difficult to raise from ordinary cuttings, is described as layering. This is done in July, by cutting half way through a node a few inches from the tip of a strong shoot, and at the cut pegging down the shoot into a firm layer of sand. From the cut surface nearest the tip new roots arise, and when these have become firmly fixed, the shoot may be removed and planted elsewhere.

A few plants, such as begonias, may be grown in pots and window-boxes from leaf-cuttings. Thick, healthy leaves are



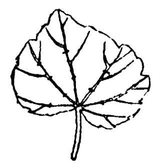


FIG. 71.

GERANIUM CUTTING IN POT.

BEGONIA—UNDER SURFACE OF LEAF SHOWING POINTS (A) AT WHICH VEINS MAY BE CUT ACROSS.

removed from the parent plant and one or two cuts are made across each vein on the lower surface of the leaf, which is then pressed down firmly on to the surface of sand or fibre, such as is used for growing bulbs. At each cut a callus is formed, and roots and shoots are produced. When the young plants are growing sturdily, they may be separated and transplanted into other pots or boxes.

Some of the slender, weak-stemmed plants which will grow in window-boxes· may need support. Carnations and canary-creeper may be tied with bast to strong, thin strips of wood, described as stakes, which are pushed down firmly into the soil close to the plant. Tie the bast loosely and cut the free ends neatly, so that it is not seen more than is necessary. Other plants, such as nasturtiums (except the dwarf variety), creeping Jenny, small-leaved ivy and arabis, may be allowed to trail or scramble over the front edge of the box. Always remove dead flowers and leaves when necessary. Choose your plants so that there will be some in flower during each season of the year. In autumn you may plant bulbs and corms for spring flowering, so that you may have plants in flower from the early crocuses and snowdrops in February to tulips in May and June. When these have finished flowering, remove the bulbs and transplant seedlings raised indoors. Wallflowers bloom in spring and autumn, while asters and antirrhinums will flower throughout summer and autumn. Change the soil in the boxes every year after the summer flowers are over, and when the bulbs are planted, a few dwarf shrubs, such as juniper, spindle-tree, and other Japanese varieties, set in the boxes at the same time, will provide decoration until the bulbs flower. By these means you may grow plants for decoration throughout the whole year.

PRACTICAL WORK

Make large drawings of the cut surface, and name all the parts of each of the following objects cut longitudinally through the centre:—

1. An onion.
2. A Brussels sprout, or a cabbage.
3. A bud of horse-chestnut, or of any other tree.
4. A rose bud, or any other large flower bud. Compare your drawings and say what inference you draw from them.
5. Examine and draw a snowdrop bulb. Describe the way in which the fleshy leaves are formed.
6. Draw a longitudinal section of a crocus corm. Name all the parts.
7. Draw a longitudinal section of a prickly-pear cactus, and compare it with your drawing of the crocus corm. What inference can you draw?
8. Cut as many different kinds of bulbs and corms as you can, and put a few drops of iodine on the cut surface. Make lists of the bulbs and corms which contain starch and those which do not.

9. Examine a nasturtium seed, draw its various parts, and say whether it has two cotyledons or one.

10. Draw a nasturtium seedling at different stages of growth. Label the parts in your drawing.

11. Grow climbing nasturtiums in a pot and provide them with stakes for support. Find out by what means they climb.

12. Examine various climbing plants, and note the methods by which they climb.

EXERCISES AND QUESTIONS

1. Describe the way in which the fleshy leaves of an onion are formed.

2. How are the scale leaves of an onion, a snowdrop bulb, and a crocus corm produced?

3. Why is it possible to grow bulbs and corms without supplying them with anything but water?

4. How are new bulbs produced by the onion?

5. How does the snowdrop produce new bulbs?

6. How do new corms grow from old ones?

7. What is meant by a cutting? Name any plants from which cuttings may be made, and say how you would make them.

8. Describe the best method of growing new carnation plants.

9. Why is it necessary to see that flower-pots are quite clean and dry before use?

10. What is the reason for the hole in the base of a flower-pot? Why is the hole covered over with crocks and not with soil?

11. Why is it necessary to change the soil in window-boxes and flower-pots once a year?

12. How would you try to ensure a succession of flowers in your window-boxes?

CHAPTER XII

HOW TO GROW PLANTS FOR EXPERIMENT

WHEN walking along the country lanes and through the fields in the late summer and early autumn you will find fruits and seeds of many different kinds of plants. Take with you envelopes of various sizes, including small wage envelopes for tiny seeds, and collect as many ripe fruits and seeds as you can. Keep the different kinds separate, and write the name of each on the envelope directly you have collected the seeds. It is very important that this should be done at once, for by the time you have reached home you may have forgotten their names or else will have mixed them.

In Chapter V you may learn how to distinguish a fruit from a seed. In the following experiments the growth of plants from seeds will be described, but when a seed cannot be separated from the wall of the fruit, as in wheat, maize, and some other fruits, or when it can only be separated with difficulty and with the probability of injury to the seed, as in tiny fruits such as those of the daisy and caraway, the whole fruit should be treated in the same way as a seed. You will then be able to see how the growing plant throws off, or grows out of, its coat and overcoat, by treating your seeds or fruits in one of the following ways:—

1. Spread small seeds, such as mustard and cress, poppy, and hemp seeds, on clean, damp blotting-paper or rag on a plate. Keep the paper or rag always moist.

2. Float cotton wool on water in a tin or dish, and put on it date-stones or fruits of maize, wheat, sunflower, pea, or other seeds or fruits of about this size, which have been

soaked for a day in cold water. Date-stones may be soaked for three or more days.

3. Pour some water into a bowl and then add clean sand or sawdust gradually, stirring all the time, till you have made it into a stiff "mud pie". Put the mixture into flower-pot saucers, or into wooden boxes with a few small holes bored at the bottom, and plant peas, beans, or any other seeds in rows about an inch apart.

4. Soak acorns or chestnuts well in cold water for one or two days, and then rest them in the narrow neck of a bottle nearly filled with water, so that the water nearly touches the seed.

5. Soak nasturtium seeds, peas, or beans for a day in cold water. Line the inside of a glass jam-pot with damp blotting-paper, and put the soaked seeds between the paper and the glass. Keep the blotting-paper moist.

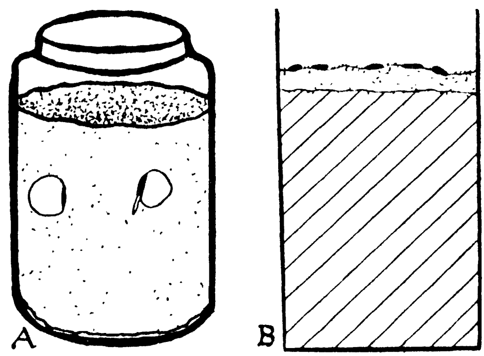


FIG. 72.

A. Seeds germinating in pot lined with blotting-paper.
B. Seeds germinating on cotton wool floating on water.

All these methods of sowing seeds enable you to see the beginning of growth and to observe how it goes on till the young plant is well developed. If you wish to keep your plants you must transfer them to soil soon after the root and shoot appear.

Always keep accurate records of your experiments. The easiest way to do this is to rule a double page of your exercise book into eight columns. Make the first seven an inch wide, and leave the last a very wide one for notes, as in Table I.

In the column for notes put, if you can, the highest and lowest temperatures of the place where the plants were grown, but if you have no thermometer, note whether the room is cold, very cold, moderately cold, or warm, very warm, or

TABLE I.

Kind of Seed.	Time of Soaking.	When Sown.	Where Sown.	When Seed Coat Burst.	When Root Appeared.	When Shoot Appeared.	Notes.
Sweet pea	24 hours	August 2, 1928	On cotton wool	August 3, 1928 while soaking	August 5, 1928	August 7, 1928	Average temperature 56° F.

TABLE II.

Kind of Seed.	Group.	Time of Soaking.	Planted in	Date of Planting.	Shoot Appeared.	Notes.
Broad beans	A	24 hours	Dry sawdust	May 4, 1928		
	B	24 hours	Damp sawdust	May 4, 1928	May 18, 1928	Fairly cold
	C	—	Dry sawdust	May 4, 1928		
	D	—	Damp sawdust	May 4, 1928		

moderately warm. Note, too, whether the days are sunny or dull, and whether the seeds are in a light, dull, or dark place.

If the seeds be sown out of doors, you may be able to obtain the temperatures from a daily paper, or from the ink thermometers found in many localities outside stationers' shops.

The growth of the plant from the seed is called *germination* (L. *germen*, a bud).

Make drawings of the stages in the germination of the seeds, and date all your drawings.

You will probably find that some of your seeds fail to germinate. This may be due to some fault in the seed itself; or it may be because you have not given the seed the things it needs for germination. You can discover its needs by carrying out the following simple experiments:—

6. Soak some seeds for twenty-four hours, and divide them into two equal groups, A and B. Plant group A in dry, and group B in clean, damp sawdust. On the same day plant equal numbers of dry seeds of the same kind: one group, C, in dry, and the other, D, in damp sawdust. Label each group as you plant it, and make a complete record of your results as shown in Table II.

Sand, soil, rag, or blotting-paper may be used instead of sawdust, but in any case the four groups of seeds should be kept close together in the same part of the room; so that the only difference in their treatment is in the amount of water they receive. You will readily see the importance of this by making a simple comparison with your own behaviour. Suppose you sit on a pin and at the same time bump your head. You cry out, and an onlooker who knows nothing of the pin thinks you made a noise because you bumped your head. The true explanation may be that the pin hurt so much that you did not notice the bump, or on the contrary that the bump hurt so much you did not feel the pin, or that both were hurting you; so that your cry of pain might have been due either to one cause alone or to both causes together.

Similarly, if you put one set of damp seeds in a warm place, and a set of dry seeds in a cold place, you will be unable to say whether the moisture or the warmth, or both, affected your results.

7. Soak twelve peas or broad beans for twenty-four hours; then dry them thoroughly with soft rag or blotting-paper. Completely cover six of them with rubber solution of the kind used for mending punctures. Put these seeds in a glass jam-pot lined with damp blotting-paper, as described in experiment 5, and put the other six seeds in a similar jam-pot close beside the first. Look at both sets of seeds every day, and if the rubber solution show signs of soaking or peeling off, replace it with a fresh layer.

At the end of a week take one of the rubber-coated seeds, remove the seed-coat very carefully, and replace the seed in the jar. At the end of the second week similarly remove the testa from another seed, and replace the seed. Do this every week until all the seeds coated with rubber have had their testas removed. Keep daily records of the growth of both sets, and try to account for the results. Remember all the seeds were first soaked, and all have been kept at the same temperatures and under similar conditions. What has been kept from the seeds by the rubber solution?

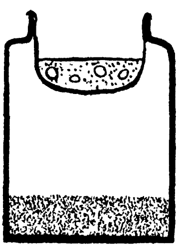


FIG. 73.—APPARATUS FOR EXPERIMENT 8.

8. Soak a dozen peas for a day and then carefully remove their testas without injuring the seeds. Suspend a piece of damp butter muslin from the neck of a glass jam-pot containing water to the depth of half an inch. Put six seeds in the muslin and tightly cork the jam-pot; or glue parchment paper over the top.

Into a similar jam-pot put a solution of caustic potash. Have the other peas in muslin ready to hang in the jar, and the cork or parchment paper and glue ready to close the top. Now add a small amount of pyrogallic acid to the caustic potash solution, quickly hang in the peas, and close the jar. The pyrogallic acid is a white crystalline solid, and a small quantity of it may be bought for a few pence from the chemist. Use about as much as will cover a penny. The acid combines with the caustic potash, and the solution absorbs the oxygen from the air, so that the seeds in this bottle get no oxygen.

9. Soak some seeds for twenty-four hours. Divide them into three equal groups, and put each into a jam-pot lined with blotting-paper (see experiment 5). Put one jam-pot as near the fire as possible, but where the heat is not sufficient to cause the jar to break. Put the second in a warm room, and the third in the coldest place you can find. Keep all the seeds moist, and record the results every day.

10. Soak some seeds for a day, and divide them into two equal groups. Spread each on damp blotting-paper or cotton wool (see experiment 1), or put them in a jam-pot lined with blotting-paper (see experiment 5). Put one set near a window and the other in a dark cupboard, and keep both as nearly as possible at the same temperature.

If you have carried out these experiments properly you will have discovered that to enable it to germinate a healthy seed must have:—

(*a*) **Sufficient moisture** (experiment 6).
(*b*) **Oxygen**—from the air (experiment 7).
(*c*) **A suitable temperature** (experiment 9).

Experiment 10 will have shown you that seeds will germinate in light and in darkness. Water, oxygen, and sufficient warmth are the only things necessary for the germination of most seeds; but a few seeds, such as those of orchids, need in addition a certain fungus which grows inside them and helps them to grow. Without the aid of this fungus or of special food material such as sugar solution, orchid seeds will never germinate.

EXTRA PRACTICAL WORK

Sketch and date all the different stages in the germination of

1. Maize.
2. Wheat.
3. Date-stones.
4. Onion seeds.
5. Sunflower.
6. Acorn.
7. Horse-chestnut.
8. Sycamore.
9. Apple.
10. Plum.
11. Orange.
12. French bean.
13. Broad bean.
14. Pea.
15. Castor-oil bean.

EXERCISES AND QUESTIONS

1. Make a list of all the differences in the germination of maize and the sunflower seed.

2. Which of the seeds named in exercises 1 to 15 have food stored in the cotyledons?

3. Which of the seeds named in exercises 1 to 15 have cotyledons which never come above the soil?

4. Write down the plants, named in the practical exercises 1 to 15, which belong to the class Dicotyledons.

5. Why does a farmer store his grain in a dry place?

6. Explain why, when experimenting with plants, or animals, it is necessary to change only one condition at a time.

7. What conditions are necessary to allow a healthy seed to germinate?

8. Describe an experiment to show that light does not affect germination.

9. How may oxygen be removed from air?

10. Is it better to use dry or soaked seeds for experiments? Suggest uses for the water in the soaked seed.

CHAPTER XIII

HOW TO STUDY THE FEEDING OF PLANTS

JUST as animals, irrespective of their differences in structure, may be divided according to their diet into vegetarians and non-vegetarians, so plants may be divided into two big groups having very different methods of feeding. In one group are included all the plants containing chlorophyll, in the other all those with no chlorophyll.

The feeding of all green plants has already been described in connection with *Chlamydomonas*.[1] How is it possible to show that green plants need the elements mentioned there, and that they use them to produce complex foods? Here is a series of experiments which should enable you to find whether certain elements be necessary to the plant: in every experiment handle the plant carefully and as little as possible. Sketch all your apparatus, note the date of beginning the experiment and the time taken to obtain a result. Record the weather conditions if they affect the plant: note particularly the temperature and the amount of sunlight.

First of all we will consider the questions arising in connection with water.

1. Does the plant need water?

Take two similar plants of any kind. Place one with its root (if it have one) in water, and the other with its root in a similar vessel containing no water. If you use algæ for the experiment, leave some in water and some in air in a similar vessel. If you use a fungus it will be better to put it on damp

[1] Chapter III, pp. 24, 25.

blotting-paper in a jar and leave a similar fungus on dry blotting-paper in a similar jar. Leave the plants until you get a result. Some plants can resist drought for a much longer time than others and may take a few days to show any effect.

2. Can the plant survive, given pure water?[1]

Any plants may be used for this experiment, but results will be obtained most quickly by using seedlings which have just finished using the endosperm or the food in the cotyledons. Take two similar plants, wash the roots of one of them well with distilled water to remove any adhering soil, and put the root in distilled water. Put the other plant with its root in a similar vessel of tap water and leave the plants until a result is obtained. This experiment may be a long one, because some plants have so much food within them that they may continue to live in the distilled water for weeks before they have used all their food store. It may be necessary to add more water, but be careful to label your plants clearly and give distilled water only to the one plant and tap water to the other.

3. Which mineral salts are necessary?

To answer this question a whole series of experiments must be done. Young wallflower plants are very suitable, or any seedlings which have just used the food store that was in the seed. Select nine similar seedlings, and as many similar bottles fitted with corks. Cut out a narrow strip reaching from the circumference to the centre of each cork so that the seedling, wedged in and protected by cotton wool, may be supported without injury. Pack the cotton wool very loosely near the circumference of the cork, so that air may pass in and out. Gum, or firmly tie, black paper round the outside of each bottle to keep the root in darkness and to prevent the growth

[1] By "pure" water is meant water which is chemically pure, that is, it contains nothing dissolved in it. Tap water, though fit for drinking, is not chemically pure, because it always contains dissolved mineral salts.

of microscopic plants or animals which might get from the air into the solution and help to decompose it. Label your bottles A, B, C, D, E, F, G, H, I.

A Into A pour distilled water. On the label write *Pure water.*

B Into B pour a solution made by adding to one litre ($1\frac{3}{4}$ pints) of distilled water:—

1 gramme of potassium nitrate.

2 grammes of acid potassium phosphate (potassium dihydrogen phosphate).

1 gramme of magnesium sulphate.

4 grammes of calcium nitrate.

A trace of ferric phosphate (i.e. about one-tenth of a gramme).

This solution contains all the necessary elements, except the carbon, which will be obtained from the carbon dioxide in the air, so the bottle may be labelled *Complete food solution.*

C Into C put a similar solution, but omit the ferric phosphate. On the label of this bottle write *No iron.*

D Label this *No calcium.* Instead of calcium nitrate use three grammes of sodium nitrate in making up the solution.

E Label this *No magnesium.* Use one gramme of sodium sulphate instead of the magnesium sulphate.

F Label *No potassium.* Replace the potassium salts by one gramme of sodium nitrate and one of acid sodium phosphate.

G *No nitrogen.* Substitute one gramme of potassium sulphate and four grammes of calcium chloride for the nitrates.

H *No sulphate.* Use one gramme of magnesium chloride instead of magnesium sulphate.

I *No phosphorus.* Use one gramme of potassium hydrogen sulphate in place of the phosphate.

Arrange the bottles in a row in a place where the plants will get a moderate amount of light and not be in a draught. Fasten to each bottle a long ruler, or a stick with squared paper attached, and record the height of each seedling. Arrange your records in the form of a table and make entries whenever any plant shows an appreciable change in growth.

HEIGHTS OF SEEDLINGS

	Dates of Observation.		
	May 1, 1929.	May 4, 1929.	May 7, 1929.
Food Solution—	Inches.	Inches.	Inches.
A Pure water ..	5·2		
B Complete solution	4·9		
C No iron	5·0		
D No calcium ..	5·1		
E No magnesium ..	5·1		
F No potassium ..	4·9		
G No nitrogen ..	5·2		
H No sulphate ..	5·0		
I No phosphates ..	5·2		

The first entry should be made directly the apparatus is completely fitted up, and young plants should be observed daily, and any other changes in their appearance noted.

All the elements present in the complete solution are often described as essential elements because they are found in all plants. In making up the solutions lacking some of these essential elements two new ones, sodium and chlorine in the form of chloride, have been used as substitutes. These two elements are not essential, although they are found in most plants, and they will do no harm if present in small quantities.

4. Our next question is, **How does the water or food solution pass in?**

To get some idea of this, take a funnel, or a wide glass tube such as a lamp glass, and over one end stretch a piece of pig's bladder or good parchment. Glue the edges firmly to the glass with a glue insoluble in water. Pour into the funnel or tube a strong solution of sugar, coloured with red ink to make it easily visible, and support the tube in a glass of water so that the water in the glass is level with the sugar solution. Mark the level on the tube or funnel by tying cotton round or by slipping a rubber band over it, and mark the level on the outer vessel by an ink line outside on the glass. Fit up a similar experiment, putting the water in the tube and the sugar solution in the glass, and another experiment using water in both vessels.

This experiment illustrates the process described as osmosis, that is, the diffusion of one liquid into another of different concentration. You will have noticed that in your experiments the water passed into the sugar solution much more rapidly than the sugar solution passed into the water. In fact, if the water had not become faintly pink, we should not have suspected the passage of any sugar solution into the water. In osmosis there is always a greater diffusion of a weaker solution into a stronger one. The plant, as experiment 3 has shown, takes in very weak solutions. It has, however, a means of concentrating them, so that the solution within the plant is stronger than that in the soil or pond water. Consequently the dilute food solution diffuses through the cell walls, which correspond to the pig's bladder or the parchment, into the stronger solution in the cells. The living walls of the cells tend to prevent the outward flow of the dissolved substances and also select, to a certain extent, the mineral salts which pass in so that they are present in different proportions outside and inside the plant.

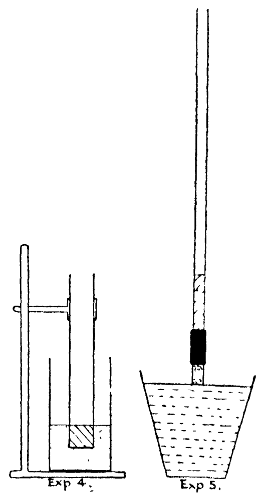


FIG. 74.—APPARATUS FOR EXPERIMENTS 4 AND 5.

You have seen that the sugar solution rises in the tube owing to the inflow of water. There must, then, have been an increase in pressure to have caused the rise. This pressure, due to osmosis, is called osmotic pressure.

5. **When the food solution has entered the root of a fixed plant, how does it get to the other parts of the plant?**

Osmotic pressure helps it a little way and the cells of the root help it still more. The walls of the outer cells become stretched when the food solution enters, and, in trying to regain their normal size, press on the solution and force it out. It cannot go back into the soil because more solution is entering, so it gets forced inwards and upwards. This pressure exerted by the cells of the root is spoken of as root pressure, and the effect of the two pressures—osmotic and root pressure together—can be shown by the following experiment :—

Put a healthy geranium plant growing in a pot in a bucket containing sufficient water to cover the greater part of the stem. Get a short piece of rubber tubing which will fit tightly over the main stem of the plant. Cut the stem under water, fasten one end of the tubing very firmly over it by winding wire round, and insert a glass tube from two to three feet long into the other end of the rubber tube and fasten it with wire. Mark the level of the water in the tube, remove the apparatus from the water, and watch the result. If this experiment be done in spring, when a healthy plant is usually growing more rapidly, the rise in level should be several inches. If, however, it be done during the autumn, and even under certain conditions at other times of the year, instead of a rise there will be a fall in level. The pressure, then, must be acting in the opposite direction and the air must be pushing the sap down. If the osmotic and root pressures together be less than the pressure of the air, the result is said to be negative, and this negative pressure will be explained after one or two more experiments have been done.

6. **Through what part of the root and stem does the water travel upwards in the plant?**

Take two similar healthy seedlings and support them by means of slit corks, as described in experiment 3, in bottles of tap water coloured with red ink. Immerse the whole of the root of one plant in the water and the lower half of the root of the other. The result will be more easily seen if seedlings with thin light green or variegated leaves be used.

When traces of the ink are visible in the leaves, carefully notice where the colour is. Cut the stem and look at the cut end. Cut the part of the root which was not dipping into the water.

In the two previous experiments we have seen that the outside cells of the root are absorbing food solution which is being forced on by the inner cells. The outer cells of any one layer cannot send water up or down because the cells of the

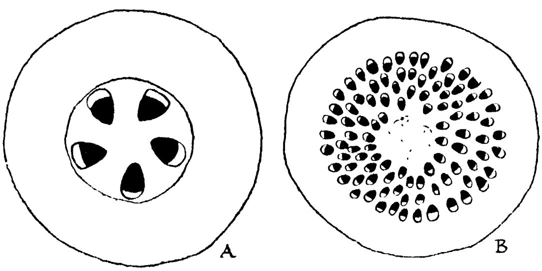


FIG. 75.—TRANSVERSE SECTION OF STEM OF (A) SWEET PEA SEEDLING (A 20), (B) MONTBRETIA (B 10). THE BLACK AREAS SHOW THE PATH OF WATER THROUGH THE STEMS OF THE PLANTS.

upper and lower layers are already engaged in passing on some of the water. All the cells must force the water toward the centre because of the incoming new supplies, and when the central part of the root is reached there is only one direction in which the solution can flow, and that is upwards. In the root and stem are certain structures called wood vessels. They are very narrow and very long compared with their diameter, and they have been formed by the breaking down of the transverse walls of columns of cells. It is much easier for the food solution to rise through these vessels than to pass through the cells in the central part of the root and stem, because it would have to diffuse through each cell wall. By putting the lower ends of capillary tubes of different bores in coloured water, you may see how the rise is helped by the narrowness of the tube. If you take a fine capillary the water will rise five or six inches.

By cutting the stem or root just above the submerged part you may find that a little of the solution has risen through the outer cells, but the passage through these cells is very slow compared with the passage through the vessels.

7. Does the plant keep all the water it takes in?

Put a leafy branch or a seedling in a small bottle of water and pour a little linseed or salad oil over the surface of the water to keep it from evaporating. Mark the water level and then cover the whole with a large glass jar. If you have a bell jar, you can use that, but if you have not, a large glass jam-pot will do just as well. Put a similar bottle of water with oil on the surface under another glass jar like the first, and put the two side by side in a moderately warm place.

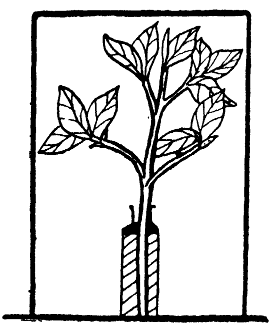


FIG. 76.—APPARATUS FOR EXPERIMENTS 7 AND 8.

The kind of branch you have used will partly determine the time required to give an appreciable result, but you should get a result within twelve hours.

If these experiments have been properly carried out, the results may be summarised in the following way:—

(*a*) A plant needs water and may continue to live for a time when provided with pure water only, but will eventually die. (Experiments 1 and 2.)

(*b*) The elements essential to healthy growth are: hydrogen, oxygen, phosphorus, sulphur, nitrogen, iron, calcium, magnesium, potassium. (Experiment 3.)

(N.B.—Carbon is also essential, but this has not yet been shown.) (Experiment 13.)

Without iron the chlorophyll is lost, and no more can be made.

Without magnesium and potassium the growth is stunted and certain food stores are not formed to any great extent.

Without calcium, growth is stunted and the leaves do not develop properly.

Sulphur, nitrogen, and phosphorus are necessary to form the protoplasm of the cells, and the hydrogen and oxygen, in addition to forming part of various food substances, are necessary in the form of water to keep the cells turgid, thus helping to support the plant and to dissolve the food, making possible its transport within the plant.

(*c*) Owing to differences in the osmotic pressures of the liquids inside and outside the plant, food solution passes into the root.[1] (Experiment 4.)

(*d*) Root pressure forces the food solution, or sap, to the central part of the root. (Experiment 5.)

(*e*) Sap rises through the wood vessels in the central part of the root and stem. (Experiment 6.)

(*f*) Water vapour is given off by the shoot. (Experiment 7.)

Our next problems arise out of our last discovery.

Which part of the shoot gives off the water vapour?

8. Take five similar branches with dorsiventral leaves and put each branch in a bottle of water with oil on the surface, as described in experiment 7. Completely cover the stem and both surfaces of every leaf of the first branch with vaseline. Smear both surfaces of the leaves of the second, the upper surface of those of the third, and the lower surface of those of the fourth with vaseline, and leave the fifth untouched.

[1] Old roots are unable to absorb water because their cell walls have become too thick. By looking at any exposed roots of trees you can see that they have a very thick, hard, protective layer. Such roots either have fungi living inside them, and sending hyphæ out into the soil to absorb water, or have fungi living closely around them and sending hyphæ into the root so that water may be conveyed into it.

Cover each bottle with a bell jar or glass jam-pot, and leave them all side by side in a warm, sunny place. Observe them every half-hour and note the results.

Repeat the experiment with bifacial leaves and with plants like laurel, pine, and common evergreen shrubs which have very tough leaves, and compare your results.

9. **Does the water come from every cell, or are there special exits such as pores?**

Take two pieces of dry cobalt chloride paper and place one on the upper and one opposite it on the lower surface of a leaf. Cover each with a dry glass slide larger than the paper,

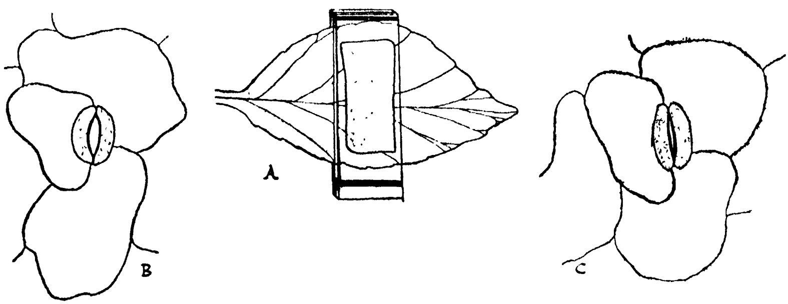


FIG. 77.

A. Apparatus for experiment 9.
B. Open stoma } of leaf of sweet pea (guard cells shaded).
C. Closed stoma }

and secure them by connecting the two slides by a rubber band at each end. In fitting up this experiment see that your hands are quite dry and work in as dry a place as possible, for the blue cobalt chloride paper changes, becoming pink directly any moisture or vapour gets to it. Watch the experiment carefully: with most leaves the result is obtained almost immediately.

When this experiment is done with the proper precautions, you will first see tiny pink spots on the paper. These rapidly spread until they meet, and often in a few minutes the whole paper is pink. The formation of the spots shows that the water vapour is not coming from every cell.

10. Strip a piece of skin from the leaf of a sweet pea, geranium, or violet, or any moderately thin leaf, and examine it under the microscope. There are many tiny openings, and it is through these that the water vapour is able to pass out. A single opening, with the two kidney-shaped cells enclosing it, the guard cells, is called a stoma (Gk. *stoma*, mouth). The other cells forming the skin are of very different irregular shapes.

11. Look for stomata on the skin of a stem. Compare the numbers of stomata on the skin from the two surfaces of a dorsiventral leaf and of a bifacial leaf.

12. **Can the plant regulate the amount of water given out through the stomata?**

Select four similar leafy branches having as nearly as possible the same leaf area. Put them in similar bottles of water with oil on the surface and mark the water level. Keep one branch indoors in a warm place free from draughts and another in a warm, draughty place—out of doors in the sun, if you are doing the experiment on a warm, sunny day. Put the third in a cold place free from draughts, and the fourth in a cold draughty place.

Compare the fall in the water level in the four cases, and try to explain the results.

From these further experiments you should have discovered:—

(*a*) The plant gives out water in the form of vapour. (Experiment 7.)

(*b*) Openings, with the special cells enclosing them, form stomata and allow the water to pass out. (Experiments 9, 10.)

(*c*) Stomata are fewer on the upper surface of a dorsiventral leaf. (Experiments 8, 11.)

(*d*) A bifacial leaf has the stomata approximately equally distributed over its two surfaces. (Experiments 8, 11.)

(*e*) On the stems of leafy branches of herbs there are fewer stomata than on the leaves. (Experiments 8, 11.)

(*f*) The amount of water given out by the leaf is regulated. More passes out in warm air than in cold, and more is carried away by moving air than by still air. (Experiment 12.)

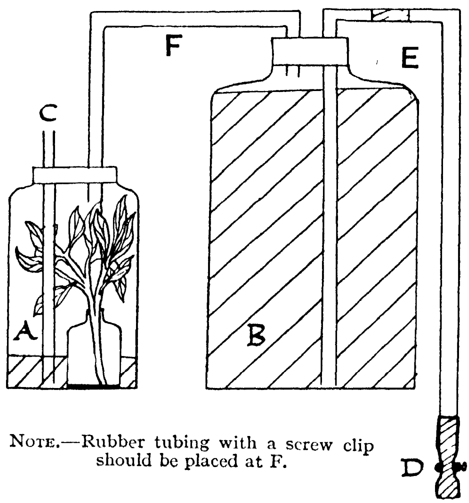
This regulation is performed by the guard cells which have thin walls except round the opening, where they are thickened. When the plant has a good water supply, the cells become filled with sap and distended. Since the thickened parts of the guard cells resist the pressure of the sap, they cannot be forced into the opening, so the thin parts of the walls get forced in the opposite direction, and, pulling on the thick parts, make the opening wider. Below each stoma is an air space, and into this the cells give off the vapour, which passes out. When less water is procured by the plant there is less force in the guard cells, so the thin walls cease to pull on the thicker parts and the opening becomes much smaller.

This process of giving off water is described as transpiration, and it is one of the many processes helping to raise the sap through the stem to the leaves. As the water evaporates, more rises to take its place, and so there is, in a healthily growing plant, a continuous upward current of water. In the autumn, however, the leaves of many plants wither and fall off, and if experiment 5 be done when this is happening, or when, for any other reason, transpiration is feeble, the result will almost certainly be a negative pressure because the upward pull due to transpiration has been lost.

You should be able to think of a number of other simple experiments to show transpiration: only a few have been suggested here.

13. **How can we show that carbon dioxide is essential to green plants?**

This may be shown with very simple apparatus provided special precautions be taken to see that all the fittings are absolutely air-tight. Take two large bottles—jam-pots will do if you have nothing larger—and fit them with two-holed corks. Rubber stoppers are best, but if you cannot get them you can make corks air-tight by coating them with vaseline after the apparatus is fitted up. Fit the corks with glass tubing as shown in Fig. 78, and in the bottle "A" put a strong solution of caustic soda or caustic potash to the depth of about an inch. Stand in it the bottle of water in which is a leafy branch, and make sure that no caustic soda touches the plant. Choose a branch with fairly thin leaves, like those of lilac. Fill the bottle "B" with water, and when the apparatus is all fitted together and quite air-tight, suck water into the tube "E", which has at the end a piece of rubber tubing with a screw clip. Adjust the clip so that the water drops out of the tube. As it does so, air enters the tube "C" and bubbles through the caustic soda solution which removes the carbon dioxide. When the bottle of water is empty, close the rubber tubing at "F" by a screw clip to prevent air from entering "A" while you refill the bottle. If you continue the experiment long enough the branch will die, but the time taken will depend on the food store.



NOTE.—Rubber tubing with a screw clip should be placed at F.

FIG. 78.—APPARATUS FOR EXPERIMENT 13.

If you work in a well-stocked laboratory you may be able to use a proper aspirator to draw the air through the apparatus, and to put the caustic soda in a separate bottle,or a U-tube through which the air passes before it enters "A". This should remove the possibility of the caustic soda getting on the plant.

Instead of waiting for the plant to die there is a quicker means of showing that it uses carbon dioxide.

14. Put a well-watered plant in a dark cupboard for a week. Have the apparatus described in experiment 13 already fitted up, and, as quickly as possible, put in a leafy branch removed from the plant within the cupboard. Put a similar branch in apparatus fitted up in exactly the same way, but having the caustic soda solution replaced by water. Place the two sets of apparatus side by side in a sunny place and leave them for a few hours. Then remove a leaf from each, keeping them separate, and boil them in water to soften them. Put the softened leaves into methylated spirit to remove the chlorophyll, and when they are colourless add a few drops of iodine solution. In the practical work at the end of Chapter IV it was mentioned that iodine forms a blue compound with starch.

In trying to explain your results remember that both plants were under exactly the same conditions except that the air passed through caustic soda in one case and through water in the other. What inference can you draw?

15. **Is chlorophyll necessary for the formation of starch?**

In Chapter III it was stated that the special apparatus necessary for building starch from carbon dioxide and water was in the chloroplast. To show the truth of this take a variegated leaf from a plant which has been in the sunlight for a few hours and make a sketch of it, indicating the green parts by shading. Then decolorise the leaf, as in experiment 14, and test for starch.

16. **Is sunlight necessary for the formation of starch?**

Put two similar plants in a dark cupboard for at least twenty-four hours, then quickly remove a leaf from each plant and close the cupboard. Test the leaves for starch as in experiment 14, and if you find any, keep the plants in the cupboard until the leaves show no trace of starch. Then put one plant in a sunny place and keep the other in the darkness.

After a few hours remove a leaf from each plant and test for starch.

17. Take a plant which has been kept in darkness until there was no starch in its leaves and cover a leaf with lead foil in which you have cut your initials. Press the edges of the foil very closely on to the leaf to prevent light from getting under them. Leave the plant in a sunny place for five or six hours, then decolorise the leaf and test it for starch.

18. **Do plants produce oxygen?**

Put some of the *Elodea* plants from your aquarium in some water through which carbon dioxide has been bubbled. If

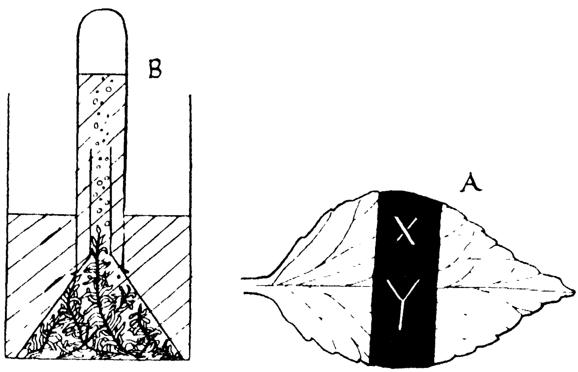


FIG. 79.
A. Leaf with strip of lead foil (Experiment 17).
B. Evolution of oxygen by *Elodea* in sunlight (Experiment 18).

you can get hydrochloric acid (spirits of salt), pour it on some chalk in a bottle fitted (as shown in Fig. 80), with a two-holed cork and glass tubing. Push the end of the exit tube down to the bottom of the water with the *Elodea*. If you should be unable to make the carbon dioxide in this way, blow through a glass tube into the water so that the carbon dioxide of your breath may be dissolved in it. Cover the *Elodea* with a funnel and put over the stem of this an inverted test-tube or small bottle full of water. To do this easily it is best to have the *Elodea* in a deep, wide jar, so that the bottle can be filled and inverted in it without removing the open end from the water. If this be impossible, fill the test-tube to the brim, close the open end with your finger, invert the tube and remove your finger when the open end is under the water in the jar. Put the apparatus in bright sunlight and watch the gas bubbles rise into the tube and displace the water. What is this gas? When the tube is full, remove it carefully by putting your finger over the open end, turn it upright, and put into it a glowing splinter. This will glow much more brightly or burst into flame, showing that the gas is not the carbon dioxide with which you supplied the plant, for if you breathe on a glowing splinter you will soon extinguish the light. The plant has used the carbon dioxide—you may verify this by testing the leaves for starch—and has produced oxygen which has collected in the test-tube.

These few experiments have been sufficient to show that:—

(*a*) Green plants use carbon dioxide. (Experiment 13.)
(*b*) Carbon dioxide is essential for the formation of starch. (Experiment 14.)
(*c*) Only the parts containing chlorophyll can form starch. (Experiment 15.)
(*d*) Starch is formed only in the presence of light. (Experiments 16, 17.)
(*e*) During starch formation oxygen is evolved. (Experiment 18.)

For the experiments described, any green plants may be used. The copper beech and plum, other plants with reddish leaves, and the red and brown seaweeds, have chlorophyll concealed by other colouring matter, and are able to feed in the same way as the plants in which the chlorophyll is visible.

The building up of complex foods from carbon dioxide is often described as carbon assimilation (L. *similis*, like), because the gas is essentially built into the plant's body substance. Since the building-up process can only go on in the presence of light, it is also called photo-synthesis (Gk. *photos*, light; *syn*, together, *thesis*, a placing).

In Chapter X examples have been given of plants having a food store of starch in parts which have no chlorophyll. How does the potato, for instance, get starch in its underground stems? The starch made by the leaves would soon fill the cells, hindering their further work, if it were not removed. The other parts of the plant, too, are doing work and need their share of the food. How is insoluble starch to be conveyed to them? It has first to be changed to a soluble substance, and it is a comparatively simple process to change starch into sugar. This change is brought about by a ferment called diastase (Gk. *diastasis*, division), and takes place mainly in darkness, so that in the morning much, if not all, of the starch has been removed from the chloroplasts, which are ready to begin to make more. The sugar is taken down to the stem in the potato, or to the root in the sago palm, and the excess is changed back into starch and stored until it is needed. The sugar generally formed is glucose or dextrose, and is much less complex than cane sugar.

The **lichens** are curious plants: each really consists of two plants, an alga and a fungus, living and growing together. The algæ present are minute unicellular plants, and hundreds of them are held in the mesh formed by the interwoven hyphæ, so that the upper surface of the lichen is green, yellow, or brown according to the kind of algæ present. The lower surface of the lichen is sometimes formed entirely by the fungus, and is then white. When the plant grows on the ground or on trees, the hyphæ absorb the mineral salt solutions, and the algæ build up the food from the carbon dioxide. So the algæ receive solutions and protection from the fungus, which in return receives the food it is unable to make for itself. This is one of the best examples of plants living together for mutual benefit.

The mistletoe, and some less widely known plants, such as the eyebright and cow-wheat, feed on carbon dioxide in the usual way, but do not grow in the soil. Mistletoe grows on apple-trees, eyebright and cow-wheat on the roots of grass, and take the solutions of mineral salts from these. Plants obtaining part of their food from others are semi-parasites, and the plants helping to feed them are called their hosts.

A further step in the direction of dependence on other plants is shown by total parasites. These have no chlorophyll, so are unable to use carbon dioxide, and have to depend entirely on their "hosts", which are usually killed eventually because they cannot support themselves and their parasites. Many fungi are examples of such parasites. A coral pink one, *Nectria*, forms small rounded outgrowths on the branches of apple-trees. A big mushroom-like toadstool, *Armillaria*, grows on the roots of pines, and another species of it on beech roots; the vine, hop, and rose mildews are other examples. The dodder is a flowering parasite appearing as small red filaments winding round gorse plants and sending small outgrowths into the gorse for anchorage and to steal the food. Another species of dodder grows on grass.

Other plants containing no chlorophyll are saprophytes (Gk. *sapros*, rotten; *phyton*, a plant), that is, they get their food from decaying plants or animals, or by absorbing complex foods provided in solution. The moulds on cheese and jam, yeast, bacteria, and the fungus causing dry rot, are all familiar examples of saprophytes. The bird's-nest orchid, the bird's nest (*Monotropa*), and the tooth wort are the commonest flowering saprophytes, and may be found in beech woods.

In various industries man makes use of the peculiar mode of feeding of yeast and of bacteria.

Yeast

Buy a pennyworth of yeast from a baker or from a brewer, mount a little of it in water on a slide, and examine it under the microscope. Like the *Chlamydomonas*, the yeast plant is unicellular, and has cytoplasm and a nucleus within the cell wall, but chlorophyll, one of the most striking features of the *Chlamydomonas*, is absent from the yeast. If you have a microscope with very good lenses that give a very high magnification, you may distinguish in some dried yeasts one, two, four, or eight rounded bodies within the cell wall. These are spores formed by the division of the nucleus and cytoplasm of the original cell, or mother cell, and each has its own wall, and so is doubly protected against drought. Sometimes only one spore is formed, and the spore coat can be seen inside the wall of the mother cell.

Crush two dozen raisins, pour 100 cubic centimetres—rather less than a fifth of a pint—of boiling water on them, and allow them to soak for an hour, stirring occasionally.

Taste the liquid: the sweetness is due to the water having dissolved the grape sugar from the raisins. Pour off the cold liquid into a wide-necked bottle, add a little yeast, and almost immediately you will see bubbles of gas rising to the surface, carrying the yeast plants with them. At the surface the bubbles escape and some of the plants fall again.

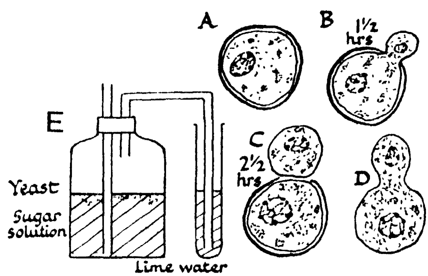


FIG. 80.

A. Resting cell.
B. Bud formed by resting cell after 1½ hours in sugar solution.
C. Separation of bud an hour later.
D. New plant budding.
E. Apparatus to show production of carbon dioxide.

If you repeat the experiment, using in an equal volume of water about half a lump of cane sugar instead of grape sugar, the bubbles will not appear at first. You may have to wait from twenty minutes to an hour or more, according to the condition of the yeast, the temperature of the room, and the amount of sugar in the solution. Fit the neck of the bottle with a cork carrying a glass tube bent as shown in the diagram, and pass the gas given off by the yeast into lime water: this becomes milky, and the gas, therefore, is carbon dioxide. Should you be unable to fit up this apparatus, dip a glass rod in lime water and hold the rod in the neck of the jar. The drop at the end of the rod will become milky. After a few hours smell the liquid containing the yeast. People sometimes describe it as smelling *fermented*. The smell is due partly to the presence of alcohol, which the yeast has produced while feeding on the sugar, and this decomposition of the sugar is known as fermentation (L. *fervere*, to boil), because of the bubbles rising through the liquid.

Wine-producers and brewers make use of this ability of yeast to produce alcohol. Grape juice is fermented to make port wine and champagne. To make beer, barley is germinated until part of the starch stored in the grain is converted into malt sugar for the young plant, which is then killed by heating it. In this condition the seed is called malt, and contains the enzyme diastase, which continues to change the remaining starch into sugar, which is used by the yeast, with the production of alcohol.

For its growth, the yeast also needs mineral salts, and quite good results may be obtained by supplying it with sugar in water containing half a gramme of tripotassium phosphate and half a gramme of ammonium sulphate per hundred cubic centimetres.

Take some of the yeast cells out of the solution while fermentation is active and examine them under the microscope. Many of the cells now have the appearance of a cottage loaf, and if you keep the plant under observation in a sugar solution you will see the parts of the "loaf" separate, forming two plants in place of one. This form of reproduction is described as budding, and while the yeast has sufficient food budding occurs very rapidly, two or more buds often being formed before separation occurs. At last, however, the yeast produces so much alcohol in the solution that it puts an end to its own growth. Bubbles of carbon dioxide cease to rise, and some of the yeast forms a scum on the surface of the liquid. The plant now forms spores, which can rest until the yeast is transferred to a fresh food solution, in which they will burst through the mother-cell wall and begin to bud.

Why does the baker use yeast? The tiny holes in bread are very familiar to you: have you ever asked how they get there? The baker mixes a little yeast with some sugar and tepid water, and leaves it in a warm place for about twenty minutes. He then mixes it with the flour, kneads the dough, and leaves it for a time to rise before he puts the loaf in the oven. The "rising" is caused by the bubbles of carbon dioxide pushing their way out, and when the loaf is in the oven the heat kills the yeast, the carbon dioxide and alcohol are driven off, and the tiny channels made by the gas remain in the bread, making it light.

The baker first leaves the mixture of yeast and sugar for about twenty minutes before mixing the dough because he uses cane sugar, and from your experiment you have seen that the yeast does not ferment this immediately. Before fermentation begins, an enzyme, invertase (L. *invertere*, to turn in) changes or inverts the cane sugar into two simpler ones, grape sugar and fruit sugar. Another enzyme, zymase,[1] now converts the grape sugar and fruit sugar into alcohol. For many years it was thought that without the living yeast cell these enzymes could not work, but it is now possible to extract them from the plant and use them.

It is impossible to separate this feeding process of yeast from the breathing of the plant, for the ferments enable the oxygen it takes in from the air to join with the sugar absorbed as food and break it down into alcohol and carbon dioxide while producing the energy necessary for growth.

From this we should expect fermentation to proceed only when the plant is well supplied with oxygen. Completely fill a bottle with a sugar or fruit juice solution, add yeast, and plug the neck with cotton wool so that there is no room for oxygen to enter, but if any carbon dioxide be produced it may escape. You will find that although fermentation goes on quite actively the yeast does not grow so rapidly as when oxygen is plentiful. Instead of being able to use all the energy for growth the plant has to use some to break down part of the sugar in such a way that oxygen is obtained to ferment more sugar in the usual way. Consequently, though more sugar is fermented the plant does not thrive as well as when it has plenty of air.

[1] See Chapter IV, p. 56.

Make up a large quantity of the solution of ammonium sulphate and tribasic potassium phosphate (0·5 per cent. of each in distilled water) and use it for the following experiments:—

19. Put 50 cubic centimetres into each of ten bottles. To the first add 1 gramme of cane sugar, to the second 2 grammes, increasing the amount in each bottle by 1 gramme, so that there are 10 grammes in the tenth bottle. Put the bottles side by side in a fairly warm place, add equal amounts of yeast to each, and try to find in which one fermentation is most active, and in which it stops soonest.

20. Repeat the previous experiment, using grape sugar in place of cane sugar.

21. To each of two bottles containing 50 cubic centimetres of the mineral salt solution add 7 grammes of grape sugar and equal quantities of yeast. Put one in a warm place (about 25°–30° C.) and the other in the coldest place you can find. In which is fermentation more active?

22. Add yeast to different fruit juices, such as grape, plum, and blackberry juice, and see if fermentation occurs.

23. Germinate some barley seeds, let them grow until the radicle is about half an inch long, and then dry them in a moderately warm place. You could do this by leaving them in the warm (but not hot) oven, after the fire has gone out. Crush the seeds with water and add yeast.

Repeat the experiment by adding yeast to crushed ungerminated seeds and water. Test one of the seeds for starch.

What change has been effected during the germination of the seeds?

24. Fill two similar bottles with mineral salt solution and to each add 10 per cent. of grape sugar or of cane sugar, i.e. 10 grammes of sugar to every hundred cubic centimetres of solution and some yeast. Plug the neck of one with cotton wool; leave the other open to the air, and place the two side

by side in a moderately warm place. In which does fermentation seem to be more active? In which is growth more rapid? Which is the first to cease to ferment?

Bacteria

Many of the bacteria play an active part in fermentation. Some convert weak wine into vinegar; others make milk sour, cream fit for butter, and butter rancid or "strong". Others, during their growth, produce marked changes in colour, and indigo is formed by the action of bacteria on the soaked leaves of the indigo plant. The linen, hemp, tobacco, sponge, and leather industries all make use of the power of bacteria to decompose substances while obtaining their food and energy.

We have seen how plants feed on carbon dioxide, with the liberation of oxygen, and that animals and plants breathe in oxygen and breathe out carbon dioxide, so that the supplies of both oxygen and carbon dioxide are maintained in the atmosphere, and vary but little in amount. How is the nitrogen supply maintained when so much of it is removed from the soil by plants and from the air by various chemical industries? Green plants do not decompose the nitrates, nor the compounds they build from them, as they do their carbon compounds. Animals decompose proteids to a certain extent and produce urea, which, after excretion, is carried by drainage to a river or sea, and so is lost to the land plants. When plants and animals die, their bodies are attacked by bacteria and decomposed, the complex nitrogen compounds being broken down into simpler ones. In fact, the bacteria carry the decomposition so far that the substances produced are too simple for ordinary plants to use. You may understand that such a state of affairs is possible when you remember that carbon dioxide and water, although they contain the same elements as starch and sugar, are too simple for you to use as food in place of these substances.

The decomposition bacteria, which in this case are described as denitrifying bacteria, produce, amongst other substances, ammonia and nitrogen, and these are of no direct use to most plants. Certain other nitrifying bacteria, however, with the help of water and oxygen, change ammonia into substances called nitrites. These contain less oxygen than nitrates, and are still too simple for the use of ordinary plants. Another set of nitrifying bacteria completes the change by converting the nitrites into nitrates, and so the nitrogenous food is returned to the soil again. What becomes of the nitrogen liberated by the denitrifying bacteria? It passes into the air, and since neither animals nor plants can use it, the amount of nitrogen in the air should be steadily increasing. There are, however, exceptional plants, other bacteria, which can use free nitrogen, and these are the bacteria which enter the root of peas, clovers, and of many other plants of the Leguminosæ, and form the small tubercles mentioned in Chapter V. Protected by the roots, these nitrifying bacteria build the nitrogen into nitrates, which pass into the soil when the root decays. For this reason farmers in many parts of the country used to sow clover or sainfoin in their fields at least once in every four or five years to restore nitrates to the soil which had been impoverished by the demands of the root and cereal crops.

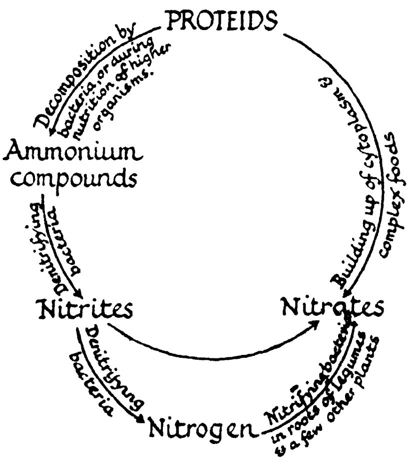


FIG. 81.—DIAGRAM TO ILLUSTRATE THE NITROGEN CYCLE.

EXTRA PRACTICAL WORK

1. Make a solution of blue vitriol. Add to it ammonium hydrate until the white precipitate first formed just dissolves, giving a clear deep

blue solution.[1] To part of this solution add a solution of cane sugar and heat it in a test-tube.

2. To another part of the blue solution add some of the sugar dissolved from raisins, and heat.

3. Dissolve 10 grammes of cane sugar in 100 cubic centimetres of water, add a little yeast, and, when fermentation has begun, add some of the liquid to the blue solution made in exercise 1, and heat. What inference can you make?

4. Put a narcissus, or other light-coloured flower with a long stem, in water coloured with a little red ink. Say, and try to explain, what you observe.

EXERCISES AND QUESTIONS

1. Two healthy plants are kept under exactly similar conditions and supplied with equal amounts of mineral salt solutions and air. One plant lives; the other dies. In what ways must the plants have differed?

2. Give an example of a plant which is able to live without air. How does it manage to do this?

3. Find out the meaning of the word "cycle", and try to explain why the process, beginning with the use of nitrates by plants growing in the soil and ending with the supply of nitrates to the soil by the action of bacteria, is described as "the nitrogen cycle".

4. What is the "carbon cycle"?

5. Devise an experiment to show that green plants use carbon dioxide.

6. Name six plants containing sugar. In which part of the plant is the sugar found, and how did it get there?

7. Two similar healthy plants are planted, one in soil containing no iron salts, and the other in soil containing iron. What changes would you expect to observe?

8. Why is it better to water plants in the evening?

9. Many plants growing in dry, exposed places either have very tiny leaves, or very thick, or hairy, or rolled leaves. What is the reason for this?

10. Many marsh plants and water plants have leaves similar to those of plants growing in dry places. Try to account for this.

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[1] Instead of this solution use Fehling's solution, if you can get it from a chemical laboratory.

11. Explain why "host" is not a good name for a plant on which a parasite or semi-parasite is growing.

12. How does a parasite differ from a saprophyte?

13. What is a saprophyte? Give six examples of saprophytes.

14. Of what use is chlorophyll to a plant?

15. Name all the things a plant needs to enable it to use carbon dioxide as food. What is the work of each?

16. What is an enzyme? Where are the enzymes diastase, invertase, and zymase found? What work do they accomplish?

17. In what industries is yeast used? In each case, what is the reason for its use?

18. What are the uses of bacteria to man? Name as many uses as you can.

19. Give an example of plants living together for mutual benefit, bacteria being one of the partners.

20. Give two examples of plants living together for mutual aid, one of the plants in each case being a fungus.

CHAPTER XIV

HOW TO STUDY THE BREATHING AND GROWTH OF PLANTS

You have often extinguished the flame of a lighted match by breathing on it. That this result is not due merely to draught may be shown by holding the match in a moderate draught of fresh air. This will cause it to burn more quickly, and if you hold it in pure oxygen it will burn still more brightly and rapidly. The air you breathe out contains carbon dioxide, and it is this gas which extinguishes the flame.

Breathe through one end of an open glass tube which has its other end dipping into lime water; the latter becomes milky, but if air be passed first through caustic soda, to remove carbon dioxide, and then through lime water, no milkiness will be produced. It is, therefore, the carbon dioxide which makes the lime water milky.

In Chapter III it has already been shown that in breathing there are three outstanding processes:—

1. Air containing oxygen is breathed in.
2. The oxygen joins with the food materials to liberate energy.
3. Carbon dioxide is breathed out as a waste product.

Can we show that when the plant breathes these three processes take place? We may show that plants need oxygen by depriving them of the gas in the following way:—

Experiment 1.

Put some healthy seedlings or some leafy branches in a non-porous jar containing the complete food solution described in Chapter XIII, experiment 3, B, and stand the jar in a large bottle containing caustic soda and pyrogallic acid.[1] Close the bottle with an air-tight cover. Fit up a similar experiment using water instead of the pyrogallic acid and caustic soda, and leave the jar open to the air. You will probably have to continue the experiment for more than a week, because within the plant are air-passages which may contain enough air to last for some time.

Experiment 2.

Repeat the experiment, using a fungus, moss, or liverwort kept on moist blotting-paper within the jar.

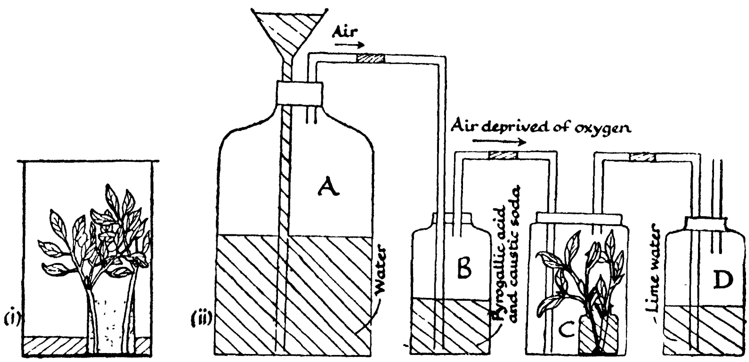


FIG. 82.
(i) Apparatus for Experiment 1. (ii) Apparatus for Experiment 3.

Experiment 3.

A better method to use for these two experiments is to fit up the apparatus shown in the diagram, and to force a continuous stream of air through it by pouring water into the bottle A, or draw air through by means of the apparatus shown in Fig. 78.

Put the solution of caustic soda and pyrogallic acid in the bottle B, so that the air passing into the bottle C, containing the plant, will be deprived of oxygen and will pass on into the bottle D, containing lime water.

Fit up a similar apparatus using caustic soda without any pyrogallic acid.

[1] Page 230.

Experiment 4.

To show that water-plants need oxygen, boil some pond or tap water in a beaker to expel air bubbles, and cool it without disturbance, to avoid including more air in it. See that the beaker is full of water, and then put into it some water plants, being careful not to make any splashes which would include air-bubbles. Cover the beaker with an air-tight lid. After a few days the plants will die. Fit up a similar piece of apparatus, using water through which air has been bubbled. Put it in darkness beside the other. Which set of plants dies first? Why should both sets die?

These experiments show that a **plant needs oxygen** to enable it to live healthily. The question now arises whether the plant obtains energy. Energy may be shown in various ways, such as growth, movement, and the production of heat.

The following experiments will help you to discover whether the plant does produce energy:—

Experiment 5.

Take a healthy pea or bean seedling with a root about an inch long, and mark it into tenths of an inch with a silk bow-string dipped in Indian ink. Make the bow by bending a flexible twig or cane into an arc, and tie across its ends a piece of silk about two inches long. By dipping this in Indian ink and using it lightly you avoid injuring the root. Fasten the bean to a cork by passing a pin through the cotyledons without injuring the plumule, and suspend the plant in a glass jar lined with damp blotting-paper. Measure the divisions every day, and make out a table recording their growth. Measure and record the length of the plumule and its daily growth.

Experiment 6.

Take a sweet pea seedling with the first leaves and tendrils just developed, and plant it in soil by the side of an upright twig or thin stick. Sketch the direction of the tendrils, put the plant in a light place, and make observations every fifteen minutes. Under favourable conditions a tendril will complete half a revolution in twenty minutes.

Experiment 7.

Moisten some flower-heads, germinating seeds, masses of roots, or any convenient parts of plants, and put them in a glass bottle so that they completely and closely cover the bulb of a thermometer. Fit up a similar piece of apparatus

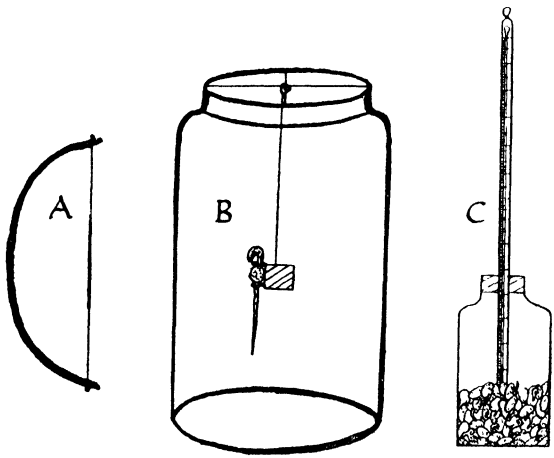


FIG. 83.
A, B. Apparatus for Experiment 5. C. Apparatus for Experiment 7.

using similar plant parts which have been killed by boiling, or use moist sand or sawdust free from any living organisms. Note the temperature of each at the beginning of the experiment and record the temperatures every half-hour.

These simple experiments show that **plants manifest energy by growth, movement, and by change of temperature.** You may find other examples of the energy used by the growth of plants in your gardens. Every plant beneath the soil has to raise or push through a considerable weight of earth before it can emerge. In churchyards the roots of trees often split heavy stones, and mushrooms have pushed up the asphalt in a playground to make their way above the surface.

We have now to show that carbon dioxide is given off, and in doing experiments with green plants we must remember that the carbon dioxide is a very important food substance for the plant, so that if the experiment be done in the light, the carbon dioxide produced in breathing will be used as food. Consequently, when using green plants or parts of plants, the experiment must be done in darkness.

Experiment 8.

Put some short, leafy branches in a jar of water in a large glass bottle. Tightly cork the bottle and put it in a dark place. Fit up a similar piece of apparatus without any branches and put it beside the other. After twenty-four hours hold a lighted match in each bottle.

Experiment 9.

Repeat experiment 8, but in the bottle containing only the jar of water put a solution of caustic soda to absorb any carbon dioxide which may be present in the air. Fill the bottle containing the branches with air which has been passed through caustic soda, and leave the bottles side by side in darkness for twenty-four hours. Open each bottle, being careful not to disturb the air inside, and hold in it a glass rod which has been dipped in lime water. Examine the drop of lime water.

Experiment 10.

If you have the apparatus shown in Fig. 82, a more satisfactory way of doing experiment 9 is to pass into lime water the air from the bottle containing the branches.

Fit up similar apparatus, omitting the branches, and leave both sets in darkness.

Experiment 11.

Repeat experiment 10, using fungi, roots, flower-heads, buds, or germinating seeds on damp blotting-paper in place of the jar of water containing the leafy branches. There is no need to put the apparatus in darkness except when using buds or flower-heads which have green parts.

Experiment 12.

Take from a tree or shrub some woody branches with lenticels not too closely covering their surface. Remove any leaves, cover the buds with vaseline, and repeat experiment 10, using in one case branches with the lenticels also covered with vaseline, and in the other branches with uncovered lenticels. If the branches be green, put the two sets of apparatus in darkness, and leave them until in one set you see a change in the lime water.

Experiment 13.

Take a small quantity of distilled water, that is, water obtained by condensing steam, and add to it a few drops of lime water. If the water become milky, take another sample, boil it to expel any dissolved carbon dioxide, and again test it with lime water; there should be no milkiness.

Into some distilled water containing no carbon dioxide, pass air which has first been bubbled through caustic soda solution, and when the water is well aerated put in it some water plants such as *Elodea*, duckweed, or algæ. Leave them in a dark cupboard for twelve to twenty-four hours, then remove them and add lime water.

From experiments 7 to 13 you should have discovered that **all parts of a plant breathe out carbon dioxide.**

The stomata of the leaves and of thin skinned stems, and the lenticels of woody stems, provide the most ready entrances for the oxygen and exits for the carbon dioxide, and the air is circulated to the cells by means of the air-passages in the plants in somewhat the same way as air becomes distributed in a house through windows or doors opening into corridors. The air-passages are much larger in aquatic plants and those living in marshy places. Roots growing in aerated soil, germinating seeds, and all the cells of the plant, breathe by the inward passage of oxygen and the outward passage of carbon dioxide through their cell walls.

Thus **the breathing of plants is similar to that of animals.** Both breathe in oxygen, use it to break down their food to liberate energy for growth, movement, and the production of heat, and both plants and animals breathe out carbon dioxide.

In trying to find the factors which influence the growth of plants, we have to consider how the plant lives, and what things are likely to influence it. We know that smoking and lack of exercise will stunt the growth of boys and girls, but since neither of these plays any part in the life of the plant, we should not consider such things in our experiments. In Chapter XIII experiments have been described to show that light and water are essential for the feeding of the green plant. It is possible that these two factors may have some further influence on growth.

To find whether light influences growth, do the following experiments:—

Experiment 14.

Take two similar straight seedlings planted in soil, sand, or sawdust, and measure their heights. Put one plant in a light place and one in darkness. Measure and record their heights daily, restoring the one plant to its dark place directly you have measured it.

Experiment 15.

Put two straight, healthy, growing seedlings one in front of a window and the other where it receives equal amounts of light from all directions. Every day compare the growth of the two seedlings.

Experiment 16.

Repeat experiment 15, using flowers of tulips or anemones on long stalks in water, and look at them every hour.

Experiment 17.

Fix a straight bean or pea seedling to a cork in the way described in experiment 5, and suspend the cork in a glass bottle lined with damp blotting-paper, leaving uncovered a narrow strip of glass about one-tenth of an inch across. Cover the outside of the bottle, except this strip, with black paper, and put the bottle with the uncovered strip of glass facing the window. Fit up a similar experiment, but cover the whole

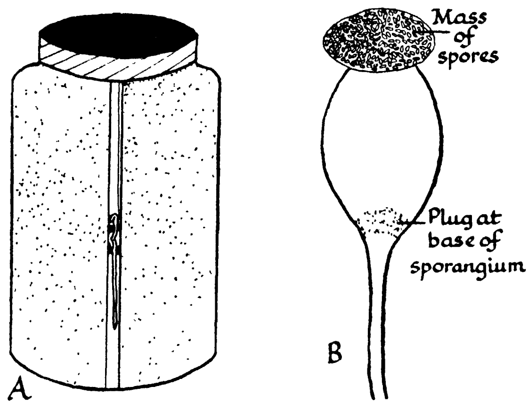


FIG. 84.
A. Apparatus for Experiment 17. B. *Pilobolus*. × 25.

bottle with the black paper. Look into the bottles every day, but do not disturb the seedling until you have obtained a definite result.

These few experiments show that **light retards growth, but is necessary for healthy growth.** (Experiment 14.)

Shoots grow toward the light (experiments 15 and 16), while **roots grow away from it.**

Many fungi are also strongly influenced by light and shoot their spores toward it. This is well shown by a small fungus called *Pilobolus*, found growing on horse-dung. It may be about a quarter of an inch high. The stout hypha has a spherical head that looks like a dewdrop with a black spot in it.

Experiment 18.

In a covered box, one end of which has been replaced by a sheet of glass, put some dung on which *Pilobolus* is growing. Put some more of the fungus in a box which is covered by glass in place of the lid. Account for the small black spots you find on the glass.

The experiment may be more conveniently done by putting the fungus under a bell jar covered with black, or thick brown, paper from which a small square has been cut out to form a "window" near the top of the jar.

Does water influence the growth of plants?

Experiment 19.

Procure a wooden box or an enamelled bowl large enough to hold a flower-pot in its centre and leave about four inches between the circumference of the flower-pot and the sides of the box or bowl. Close the hole at the bottom of the pot with a rubber stopper or well-vaselined cork. Fill the pot with water, and in the box or bowl put dry sand or sawdust. Plant in it, about two inches from the outside of the pot, a ring of soaked pea or bean seeds. Leave the experiment for about ten days, and then carefully lift out the pot without disturbing the seeds. If you see no result, replace the pot for a longer time. Fit up a similar experiment, but plant the seeds in damp sand or sawdust, and keep it moist throughout the experiment.

Experiment 20.

Plant some soaked seeds in shallow soil or sawdust contained in coarse wire gauze. Water the soil, and hang the gauze in a dry glass jam-pot (Fig. 73). Fit up a similar experiment, and hang the seeds in a jam-pot containing water. Cover the jam-pots with black paper to prevent light from affecting the results.

These simple experiments show that **the root grows towards water.**

There is also another factor that affects the growth of plants. From the next experiments try to discover what it is.

Experiment 21.

Fix a straight seedling to a cork in the way described in experiment 5, and suspend it horizontally in a glass jam-pot lined with damp blotting-paper and covered with black paper. If the seedling is growing quickly, you should have a result in a few hours. If not, leave it until you see a definite result.

Experiment 22.

Well water a young, healthy pot plant, press the soil down firmly and invert the pot, supporting the edge on either side

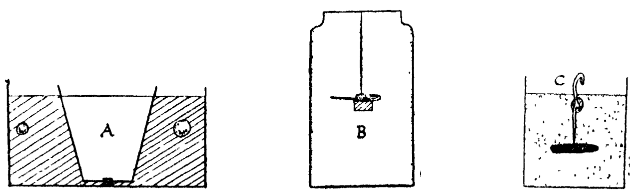


FIG. 85.

A. Apparatus for Experiment 19. B. Apparatus for Experiment 21.
C. Apparatus for Experiment 26.

by two rods so that the shoot hangs down freely between them. Leave the plant in that position until you see a marked change in the direction of growth of the shoot. Then carefully remove the plant from the soil and note the direction of growth of the roots.

Experiment 23.

Place cress, bean, or any convenient seedlings upside-down between damp blotting-paper and the side of a glass jar, and observe them every two hours.

Experiment 24.

Repeat experiment 23, after removing with a wet, sharp knife a tenth of an inch from the radicles of the seedlings.

Experiment 25.

Take a seedling which has some well-developed lateral roots, sketch it, and cut a tenth of an inch from the tip of the main root. Put the seedling in culture solution and note the direction of growth of the lateral roots. Compare the root system with the sketch made at the beginning of the experiment.

At the same time sketch a similar seedling with uninjured roots, and put it into a similar culture solution. Compare the direction of growth of its roots with that of the roots of the other seedling.

Repeat the experiment, removing the tips of the lower lateral roots.

Experiment 26.

Two inches below the surface of some sawdust place a flat pebble about an inch in diameter. Plant a seedling with a straight root about an inch long so that the root tip is vertical and just above the middle of the pebble. Keep the sawdust wet, and at the end of a week remove it carefully and notice the growth of the root. Continue the experiment until the root has grown past the pebble.

In doing these experiments, you should have discovered that **the shoot grows away from the earth and the root toward it.** The earth's influence on the plant is described as the influence due to gravity.

The movements of the plant are sometimes spoken of as tropisms (Gk. *tropos*, a turning). The movement due to light is heliotropism (Gk. *helios*, sun), that due to water is hydrotropism (Gk. *hydor*, water), and that due to the earth is geotropism (Gk. *ge*, earth).

EXTRA PRACTICAL WORK

1. Put one end of a glass tube in lime water and blow through the other end. Describe what you observe, and account for the result.

2. From outdoor observations record as many instances as you can to show that growing plants use energy.

3. Cut transversely the root of a kingcup, examine it through a lens, and compare the cut surface with that of a root of dead nettle. Account for the differences.

In the same way compare the cut surfaces of the stems, and repeat the experiment, using mare's-tail and other water plants.

4. Plant some bean seeds in a porous pot, and keep the soil moist, but not too damp. Put the same number of similar seeds in soil in a non-porous pot, stand it in a bucket of water, and when no more air-bubbles rise to the surface, remove the pot. Water it every day in this way, and compare the growth of the seeds in the two pots. Account for any differences you observe.

5. Observe the lenticels on branches of shrubs and trees, and state their use to the plant.

EXERCISES AND QUESTIONS

1. Devise an experiment to show that plants need oxygen.

2. Describe an experiment to show that green plants breathe out carbon dioxide. What difference would you make in the experiment if you were using a fungus instead of a green plant?

3. How would you show that dandelion heads produce heat?

4. What experiment would you do to show that a nasturtium or a creeper used energy in the form of movement?

5. Why should plants be removed from bedrooms at the end of the day?

6. Describe two tests you would use to detect the presence of carbon dioxide. Say which test is the more reliable, and why it is so.

7. How would you show that water plants breathe out carbon dioxide?

8. A plant deprived of oxygen breathes out carbon dioxide. Explain as fully as you can how this is possible.

9. What differences, if any, would you expect to observe in the respiration of some green peas which had been soaked in cold water for twenty-four hours, and of an equal number of similar peas which have been boiled for an hour?

10. What is breathing? Compare the breathing of *Hydra* with the breathing of *Elodea* or duckweed.

11. Which part, if any, of a root grows most quickly? How would you show the truth of your answer?

12. How would you show that germinating seeds breathe?

13. What is meant by the breathing of a cell?

14. Does a cell in the centre of a root breathe? If so, how is it able to breathe?

15. Compare the breathing of a plant cell with that of an animal cell.

16. What is the effect on a main root of removing the root-tip? Which part of the root is sensitive to the influence of gravity?

17. Devise an experiment to show that roots will grow towards water. Mention any instances where this occurs naturally.

18. How would you show that light retards growth?

19. What is the effect of putting obstacles such as stones in the way of a root?

20. Why are bulbs and seeds usually kept in darkness until they have begun to grow, and why are they then removed to the light?

CHAPTER XV

HOW TO KEEP A GARDEN

FROM Chapter XI you may find that if you grow plants indoors for decoration you must provide them with the kind of soil in which they grow best. How will you manage to do this when growing plants in the garden, where the soil may be clay or sand, neither of which is satisfactory for all kinds of plants?

Before trying to answer this question, think of some of the different soils to be found in gardens and of how soil is formed. It is composed of minute particles worn away from rocks by the continuous action of sun, rain, frost, snow, and wind, and by the action of plants and animals. This wearing away is described as the weathering of the rock. The different kinds of rock composing the earth's crust produce various types of soil as a result of their weathering. In addition to rock fragments, soil also contains the remains of animals and plants, and these remains are called humus. Usually different kinds of rock particles are found mixed together. Loam is a mixture of sand and clay, and nearly all soils contain a certain amount of chalk, or calcium carbonate. Peat soil contains a large proportion of humus.

To discover some of the distinguishing characteristics of various kinds of soil, carry out the following experiments. If you cannot find in the garden the soils required, you may obtain them from a nurseryman.

Experiment 1.

Take four tins of equal size, and bore a number of holes in the bottom of each. Fill the tins with sand, loam, chalk, and clay respectively, and suspend each over a glass jar larger than the tin. Into each tin pour the same volume of water, and when this has finished trickling through the soil, carefully measure the amount collected in each jar. Suggest an explanation of your results.

Experiment 2.

When no more water trickles from each soil in the previous experiment, spread each thinly on separate dry sheets of paper, and leave them to dry; note how long the drying takes in each case. Compare your results with those obtained in experiment 1.

Experiment 3.

Nearly fill four flower-pots each with one of the different soils named in the first experiment. Water them by standing the pots in a bath containing enough water to rise about half-way up the pots. Leave them until the soil surface is damp, then remove and allow them to drain. Sow in each some mustard seeds. Label the pots, and keep them under similar conditions, taking care that they receive warmth and air. Note in which pots the young plants appear first above the soil, in which growth is quickest, and in which strongest.

Experiment 4.

Fill an air-tight tin with water and completely immerse it in a bowl containing a measured amount of water. Mark with a narrow strip of gummed paper the new level of the water in the bowl. Lift out the tin, still full of water, and when the drops on the outside of it have fallen into the bowl, empty the tin and punch a number of small holes in its base. Push the tin, open end downwards, into garden soil, and, after pressing it well down, so that it is full, dig it out, and with a knife smooth off the surface of the contained soil, so that it is level with the edge of the tin. Lower the tin into the bowl of water, and there scoop out the soil. The water will stand at a lower level than when the tin of water was placed in it. The difference between the two levels is due to the amount of air contained in the soil, and this can be calculated by adding water from a measuring-cylinder until the level reaches the first mark.

Experiment 5.

Repeat experiment 4, if possible, using different types of soil, and compare the results with those obtained from the previous experiment.

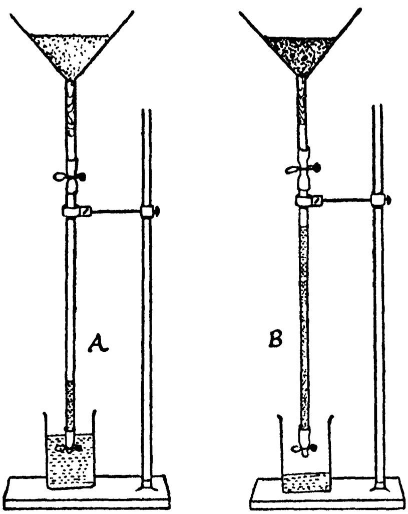


FIG. 86.—APPARATUS FOR EXPERIMENT 6.
A. Sand. B. Clay.

Experiment 6.

Plug with cotton wool the lower end of the stem of an ordinary glass funnel which has been filled with damp sandy soil. To a long piece of glass tubing attach a short length of rubber tubing closed at one end with a clip, and fill the tube with water. Connect the glass tube with the funnel by means of another piece of rubber tubing, and make sure that the apparatus is air-tight. Set up a similar apparatus, but place damp clay soil in the funnel. When both are ready, place a vessel under each and open the clips. The water will run out, owing to the passage of air through the soils in the tubes. Is there any difference between the amount of water lost from each tube?

Experiments 4, 5, and 6 show us that soil contains air, and that the amount varies in different soils. Sand is much more permeable than clay to air, as you should have found in experiment 6, since more water is displaced by the air passing through sand than by that passing through clay. Experiments 1 and 2 show us that sand is also more permeable than clay to water. This, however, may permeate the soil in two ways: it may enter from above in the form of rain, or it may be drawn up from sources below the surface soil. This power of sucking up water is described as capillarity. Compare the capillarity of various kinds of soil by carrying out the following experiment:—

Experiment 7.

Dry equal quantities of sand, clay, loam, chalk, or limestone, and peat by baking them in a hot sun. Place each sample in similar vertical pieces of wide glass tubing at least three feet long and resting in clean, dry saucers. Pour water into the saucers, and at five-minute intervals carefully measure the height to which the water has risen in each glass. The darker colour of the damp soil will distinguish it from the dry. Then make a list of the soils in the order in which the water rises, putting first the one which absorbed the water most rapidly. Your results should show that the rise of water due to capillarity is greatest in clay and least in sand.

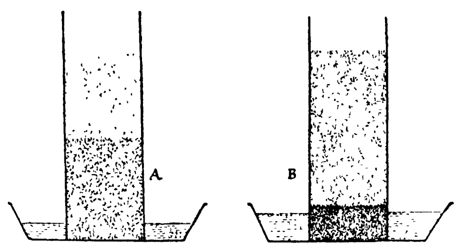


FIG. 87.—EXPERIMENTS TO SHOW CAPILLARITY OF SOIL.
A. Clay. B. Sand.

Soil contains both water and air: where and how does it hold them? The water is held as a tiny film around each soil particle, and the rest of the space between soil particles may be filled with air. Sand consists of large particles, and clay of very fine ones, and from these facts you should be able to discover why air enters and leaves sand more readily than it does clay. Also, the total surface area capable of holding a water film in clay is much greater than the total area in the same amount of sand. Hence clay will absorb a greater quantity of water than sand will absorb, and will lose the water less readily by evaporation. This is shown by experiment 3, where the plants grown in unwatered sand should wilt sooner than those in unwatered clay. On the other hand, the water film round a large soil particle is of more use to the plant than that surrounding a small one. When the water passes into root-hairs in contact with the soil, the films become thinner, and a thin film of water clings to a solid object much more firmly than a thicker one. When the films become very thin, it is so difficult to remove them from the soil particles that the root-hairs cannot use them, and so the soil may contain water which cannot be used by the plant. Since the particles of clay are so small, there will be a large film-surface of water which the plant cannot use. Under such conditions the soil is of no more use to the plant than dry soil: it *is* dry to the plant. Evaporation of soil water is greater from clay than from sand, and since the heat required to change water into vapour is taken from the soil, clay soils are said to be cold and sandy soils warm.

As neither sand nor clay is suitable by itself for the growth of most plants, is it possible in any way to change their permeability to air and water? The following experiments may help you to determine this:—

Experiment 8.

Take two similar samples of clay soil, and to one add some freshly baked quicklime. Leave both samples exposed out of doors until, by the effect of weathering, the lime has become broken up into small particles and well mixed with the clay. Repeat experiments 1 and 6, using these samples of soil.

Experiment 9.

In the same way find whether the addition of humus or peat to sand will affect its permeability to air and water.

From experiments 8 and 9 you should have discovered that the addition of lime to clay improves its texture, and that sandy soil is improved by the addition of peat or humus.

Clay soil is usually dressed with lime in the autumn, so that it is ready in spring for the use of plants. How does lime make clay soil more permeable?

Experiment 10.

On a lump of freshly made quicklime, which may be obtained from a lime-kiln, carefully pour a little water. Examine the lime after a few minutes.

You will find that the lime has crumbled and occupies more space than it did at the beginning of the experiment. In the same way the effect of rain water on the lime scattered over clay soil is to cause it to expand and crumble. When lime is mixed with clay soil, this expansion causes the soil particles to be pushed apart, and so the permeability of the soil to air and water is increased.

On the other hand, particles of sand are held together more closely by the addition of humus or peat, so that the soil becomes less permeable to air and water. By mixing together sand and clay we obtain a soil, loam, less permeable than sand and more permeable than clay, and therefore suitable for the growth of a larger variety of plants than will grow on either soil alone.

Make a rough estimate of the nature of the soil in your garden in the following ways:—

Experiment 11.

Place in a weighed vessel 100 grammes of soil freshly taken from the garden, and leave the vessel of soil to dry either in the sun or in a warm place indoors. At daily intervals weigh the vessel and its contents, and keep a record of the weights until three successive readings are the same. Find the weight of the soil at the end of the experiment, and subtract from the weight at the beginning. The loss in weight represents the amount of water lost per 100 grammes of soil. Save the soil for experiment 12.

The amount of air in the soil may be estimated by experiment 4.

Experiment 12.

In a fireproof dish, which has previously been weighed, weigh the soil saved from experiment 11. Heat the dish and its contents, vigorously stirring at intervals, until no more vapour is given off. Allow the apparatus to cool and weigh it again. The loss in weight represents the loss of animal and vegetable material, usually described as organic matter—most of which may be humus—and is the amount of organic matter in 100 grammes of your garden soil.

Experiment 13.

Take a fresh sample of garden soil, place it in a jar, add rain-water, and stir well. Notice the air-bubbles given off. Carefully pour off the muddy liquid into another jar. Add more rain-water, and repeat the process until the liquid poured off is practically clear. When the particles in the muddy liquid have settled, you will be able to compare the amount of fine particles (clay) with the quantity of large particles (sand, grit, and stones) left behind in the first jar.

Experiment 14.

On a piece of chalk pour a small quantity of weak hydrochloric acid, and make a note of the results.

Experiment 15.

Place a small amount of fresh garden soil in a strong dish, add a little water, and stir well to get rid of air-bubbles. Add about 50 cubic centimetres of weak hydrochloric acid, and compare the result with that obtained in the previous experiment.

The presence of a large percentage of chalk in the sample of soil will be shown by effervescence when acid is added. Should no effervescence take place, the soil may be deficient in chalk. The chief use of chalk is to make clay soil more permeable to air and water.

Experiment 16.

Place some damp garden soil in a watch-glass, in the bottom of which is a piece of blue litmus-paper. Leave the experiment for an hour, and then examine the paper. If its colour be changed to red, the soil will be acid. Acid soil is bad for most plants, and it may be neutralised by the frequent addition of small quantities of lime or, better, by the addition of larger quantities of chalk.

MANURES.

To supply the plant with necessary food materials, the soil must contain mineral salts which dissolve in the soil-water. These salts are derived from decaying organic substances, such as humus. Pure sand and pure clay are deficient in them, so that, to increase the amount of mineral salts needed by plants, it is often necessary to add to soil substances called manure. A good manure to use, since it contains most of the necessary mineral salts, is farmyard manure or dung. This should be spread over and forked lightly into the soil as long as possible before sowing or planting, for as it becomes broken down by weathering and by the action of bacteria the various mineral salts it contains are set free in a form suited to the needs of the plant. Fresh dung is of little use, since most of the mineral salts therein have not been made available to plants. Dung also serves to bind together the particles in sandy soil, and so improves its texture. Peat is formed by the slow decay of marsh and bog plants, and contains a large amount of humus, but, in addition, peat contains so much water that it must be drained before it can be of use to most plants. The addition of lime to it causes the setting free of ammonia, so that the valuable nitrogen it contains can be built into the nitrates necessary to the plant.

Clay soils may be improved by double digging or trenching in autumn, so that they become well drained. In double digging the soil is turned over two layers deep instead of one.

When dung is unobtainable, various so-called artificial manures may be used to make up the deficiency of certain mineral salts in the soil. Thus the nitrates necessary for the growth of the plant may be supplied in the form of sodium nitrate (Chili saltpetre) and potassium nitrate (saltpetre). Manures, such as kainit, containing potassium, help to increase the quality and flavour of vegetables and fruits, while manures such as basic slag and superphosphate of lime, containing phosphorus, help to bring about the early fruiting of plants.

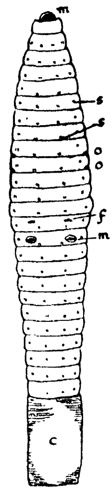
Green manure is another source of plant food, formed by digging into the soil a mature crop of such plants as clover, mustard, or vetch. They then decay, and during the process, since most crops used as green manure are rich in nitrogen, compounds of nitrogen are set free, and may be used by the growing plant.

THE EARTHWORM.

Look at the surface of the earth exposed by a railway cutting, and notice that it is composed of at least two layers. The uppermost layer forms the soil, and is usually only a few inches in depth. It may be distinguished from the underlying layers by its darker colour. This difference is due to the fact that the soil contains humus and other organic remains, while the underlying layer making up the subsoil is composed mainly of rock fragments in process of being changed into soil.

Does the subsoil ever become exposed to the action of the weather? It may do so when landslips occur, or when man cuts tunnels through it, but apart from these accidental exposures the subsoil is continually being brought to the surface by the action of earthworms. In burrowing, these useful creatures turn the soil over, so helping to bury soil and expose subsoil, and aid the formation of humus by dragging leaves into the burrows, where they decay.

Earthworms thus help to aërate the ground, and also to improve the texture of the soil, for in feeding they take soil into their digestive organs, from it extract the decaying vegetable matter upon which they feed, and eject the undigested soil through the anus in the form of worm-casts. A famous scientist, Charles Darwin, who studied the habits of earthworms for many years, estimated that in one acre of ground over eighteen tons of soil were brought to the surface in a year by these animals. If you think of the space taken up by a ton of coal in the cellar of your house, and try to imagine a heap of soil of about the same size accumulating in one year by the action of earthworms in a garden sixteen yards square, you may be able to realise how useful earthworms are in the garden.



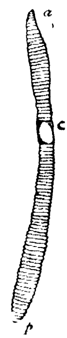


FIG. 88.

EARTHWORM — VENTRAL SURFACE OF ANTERIOR END SHOWING—

m, Mouth; *s*, Setæ; *c*, Clitellum; *o*, Openings of sperm-storing sacs; *f*, Openings of female reproductive organs; *m*, Openings of male reproductive organs.

EARTHWORM.

a, Anterior end; *p*, Posterior end; *c*, Clitellum.

Look at an earthworm, and try to suggest why it is that such a soft creature can bore through the earth. The long and slender body tapers at the ends. The posterior end is flattened from above downwards, so that, seen from the dorsal or ventral surface, it appears broader than the other end. Notice the numerous segments of the body: the earthworm belongs to the group described as segmented worms. Place a worm with the darker dorsal surface upwards on the palm of your hand, and gently pull the body backwards across your palm. You will feel that the ventral surface is not perfectly smooth, but seems to be covered with numerous tiny bristles which catch against your skin. There are four pairs of these bristles on the ventral surface of each segment, except the head, and they are extremely useful for purposes of locomotion. The worm glides along, and by watching carefully you will see that it alternately stretches forward its head and draws up the tail, and the part which is being pushed forward always appears thinner than the other. This movement and change in diameter is caused by the action of two sets of muscles, an outer layer arranged in circular bands just beneath the skin and an inner layer of longitudinal muscles running from head to tail.

Hold one end of your pencil or a stick so that the other rests firmly on your desk and is pointing forward. Keeping this end fixed in the same position, move the top of the pencil until it is vertically above the fixed end, and then continue to move until the end you hold is well in advance of the other. The pencil is now pointing backward, and its lower end has remained fixed throughout the experiment. Keep your hand in the position it has reached, slip your pencil up through your fingers, and then point it forward again ready to repeat the movement. Your pencil represents the bristles, your hand and arm the worm. Similarly, the worm moves forward on its anterior bristles, and then, by withdrawing them into tiny ventral pockets, pulls them out of the soil after drawing up its posterior end and fixing the bristles on it into the soil. This end then moves forward in the same way. When the worm moves on paper, you can hear the scratching of the bristles on the surface. The worm can thus move easily over a rough surface, but movement is impossible on a very smooth surface, where the bristles cannot grip.

After a shower you may often find earthworms projecting from their burrows, but if you approach very, very lightly and try to remove one you will find it extremely difficult to do so. The body is fixed very firmly, the broad tail end being pressed against the walls of the burrow, and the least vibration of the soil is sufficient to cause the disappearance of the worm into it.

Look at the head end, and notice that there is a mouth, but no structures resembling eyes and ears, for the earthworm does not possess them. How then does it sense your approach? Scattered over the body, especially at the anterior end, are sensitive cells, by means of which the animal can feel vibrations, and can also distinguish between light and darkness, since it mostly remains underground during the day and emerges at night. On account of this sensitivity and the absence of sense organs, the earthworm is said to be diffusely sensitive.

Perhaps you do not like handling earthworms because they feel so moist and slimy. The slime is secreted by glands in the skin, and serves many useful purposes. It acts as a cement, helping to bind together the walls of the burrow, and is poisonous to the smaller enemies of the earthworm, such as soil bacteria, which would otherwise attack it. Further, since the worm breathes through the whole surface of the body, the slime serves to keep the skin moist and so aids respiration, in much the same way as the secretion from the skin of the frog. The body is covered with a very thin cuticle secreted by the cells of the epidermis, and in this cuticle are numerous fine grooves crossing each other at right angles. The peculiar rainbow-coloured sheen of the skin, spoken of as iridescence, is due to the special way in which these grooves interfere with the rays of light.

Look at the ventral surface of a large worm, and count the segments carefully from the anterior end until you reach the fifteenth; on this you should be able to see two tiny projections, each having a pore. These are the openings of the male reproductive organs, and on the fourteenth segment you may see, with the help of a lens, two very small openings, those of the oviducts, through which the eggs escape. Both male and female reproductive organs are found in the same earthworm. Count back to segment eleven, and between this and the tenth segment, and between the tenth and ninth segments, you may find a pair of tiny openings leading each into a sac in which spermatozoa received from another worm are stored. Nearly half-way along the body you will see a much swollen portion, a band of smooth glandular tissue covering five or six segments, and called the saddle or clitellum. The spermatozoa produced by one earthworm are given to another before the eggs are ripe, so that self-fertilisation cannot take place. When the eggs are ready to be shed, the worm wriggles backwards through the clitellum, which becomes loose, and receives the egg cells when it reaches the fourteenth segment. As the clitellum passes forward over the remaining segments it receives the contents of each of the sperm-containing sacs, and is then slipped off the head end of the worm. The clitellum becomes a cocoon, its ends closing together, and within it the egg-cells are fertilised each by a spermatozoon. The cocoons are small and yellow, and are found usually in spring and summer under stones and in other sheltered places. The eggs develop inside the cocoon, and from them one or two tiny earthworms eventually emerge.

On the ventral surface of the body are tiny pores, two on most segments, but extremely difficult to find even with the aid of a lens. These are the openings of the kidney tubes, a pair being present in all segments except the first three and the last one. On the dorsal surface are other openings, the dorsal pores, one between every two segments, and these also are very difficult to find; through them a fluid escapes from the body cavity of the worm. At the tail end is the opening of the alimentary canal, the anus.

The earthworm has many enemies, the chief ones being birds and moles. Occasionally, too, human beings may be counted as enemies, but all true gardeners should appreciate the help they receive from worms and protect them. Even when he accidentally cuts one in two with his spade, the sensible gardener leaves the pieces in the soil, for he knows that one part may grow a new head end and the other a tail end, and so the worm is not killed.

Vegetative Propagation.

Many of the plants you may grow in your garden can be produced from seeds sown in the way suggested in Chapter XI for window-boxes. Others, though they may produce seeds which will germinate, grow better from vegetative structures, such as bulbs. In such cases the plant is said to be reproduced by vegetative propagation. Bulbs, corms, and tubers are often separated from the parent plant before they produce new plants, and so in them we find a certain amount of food material stored. Some plants, however, reproduce vegetatively, and the young plants remain connected with the parent until they are well rooted, so in these we do not find a special reserve of food material. When you wish to have a strawberry bed in the garden, you set a few strawberry plants in the spring, and by the autumn the number of your plants has increased. How was this possible? Since you usually pick and eat all the fruits produced by the plants, there is little chance of new ones growing from seeds. If you examine one of the smaller plants, you may find that it is attached to a larger plant by a tough stem-like structure bearing tiny scale leaves. These structures are true stems, since they bear leaves, and are called runners or stolons. Each is produced in the axil of a leaf of the parent plant. In the summer you may see several slender shoots bearing scale-like leaves arising from one plant. They spread out over the surface of the ground, the internodes lengthen, and a runner is produced. The tip of the runner eventually produces a new plant, with adventitious roots and a rosette of leaves. Fresh runners grow from the axils of these leaves, and other new plants are produced. Eventually the plants are separated by the decay of the part of the runner connecting them. The runners of the house-leek are very short, and are known as off-sets.

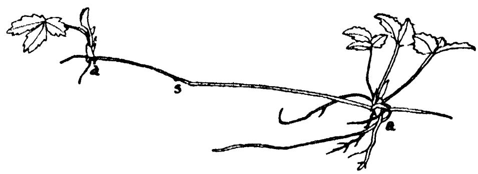


FIG. 89.—STRAWBERRY PLANT WITH RUNNER. × ⅓.
a, Adventitious roots; *s*, Scale leaf on runner.

Mint reproduces usually by means of suckers. These are shoots produced similarly to runners, but they grow some distance underground before the tips turn up and give rise to new plants. The suckers produced in fruit trees, such as the apple, or by the loganberry and raspberry, grow for only a short distance underground, so that the daughter plant is not very far removed from the parent.

Sometimes a blackberry branch may arch over until its tip touches the ground, when it grows and gives rise to numerous adventitious roots. From the axils of small leaves found among these roots new shoots arise, and when these are well developed the arched branch dies and they become free.

You may also grow plants from cuttings by the method described in Chapter XI. These provide another means of vegetative propagation. Cuttings of woody stemmed plants, such as gooseberries and currants, should be made when the twigs are leafless, in October or November. The peony, Japanese anemone, and several other plants will grow from root-cuttings. In spring or autumn the roots are cut into lengths of about three inches, and when these are planted in sandy soil and left in a warm, sheltered place, each cutting will produce young shoots and adventitious roots, and may then be planted out of doors in the garden.

In budding, another form of vegetative propagation, a bud from one plant is inserted into another plant of the same genus and grows, producing a shoot. It is a common method of propagation of roses, which do not grow readily from cuttings, and it is usually carried out in June or July. Budding should be performed in dull, showery weather. The best day to choose is a warm, dull day following a period of rain. As the success of budding depends upon the freshness of the bud when it is inserted in its place, it is necessary to have all your tools ready beforehand. These will include a sharp knife with a smooth edge and some bast. Choose a dormant bud from a healthy shoot that has finished flowering, and cut the surrounding leaf-stalk just above the stipules. To remove the bud, cut off with it a thin layer of the stem, the shield, extending about three-quarters of an inch above it and the same length below. Hold it by the stipules in the left hand, and with your thumbnail quickly separate and remove the woody part, being careful not to injure the bud. Shape the lower edge to a point, and place the bud in your mouth to keep it moist while you prepare the stock in which you are going to insert the bud. Make a T-shaped opening in the bark of a short, healthy shoot, cutting only through the bark, and fold back the cut edges gently with a flat knife-handle. The short cut should measure about half an inch, and the longer one an inch. Insert the bud in the opening, and gently press the shield into position under the bark of the stock, cutting the top of the shield level with the short edge of the cut so that the inner surface of the bark of the shield fits closely against the wood of the stock. Bind the bud into position with bast, which should be wound round the stem, first above and then below the bud, above and below again, this being repeated until the cut is covered, when the ends are tied firmly and neatly clipped. If the budding be successful, the tissues of the two plants will grow together, and the bud will develop in the following spring. In this way you may produce a favourite variety of rose on a stock which would otherwise produce poor blossoms.

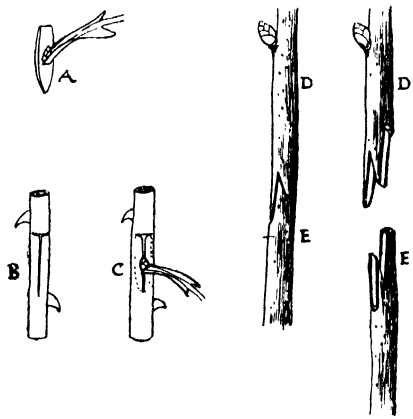


FIG. 90.

BUDDING.
A. Bud with shield.
B. Stock with T-shaped cut.
C. Bud inserted in stock ready for tying.

WHIP AND TONGUE GRAFTING.
D. Graft.
E. Stock.

In grafting, a whole shoot is transferred from one plant, usually a tree, to another tree. The shoot may be cut and fixed in various ways to the stock, one of the commonest ways being known as whip-and-tongue grafting. For this method, a year-old shoot showing several buds is cut from the tree. The top of the shoot or graft is removed with a sharp knife, and its base cut into a form somewhat resembling the letter N. A shoot of the stock of about the same thickness as the graft is shaped in the same way by cutting off the tip. The cut surfaces are placed together and should fit exactly, and the graft is tied into position with bast, the joint being covered with clay or wax to protect it from undue loss of moisture and from attack by bacteria or other organisms causing disease. Grafting is carried out in spring, when the tree is growing vigorously, and by means of this process new varieties of fruit may be produced.

WEEDS.

You will probably find springing up in your garden plants other than those that you planted. Such plants may be classed as weeds, that is, plants growing in the wrong place. A farmer might admire poppies growing in his garden, but dislike them in his cornfields, for there they are growing where his corn should grow, and are therefore weeds. If unchecked, weeds spread rapidly, and this is partly because most of them are annuals, and the majority produce large quantities of seeds. Shepherd's purse, for instance, produces seeds and grows so rapidly that several generations of plants may be produced in one season. Weeds which do not reproduce so easily by seed are usually perennials, and may have a creeping rhizome which increases rapidly and branches, so that a tangle of plants is formed and is very difficult to remove. Other perennials, like the dandelion, have roots growing deeply into the soil. Such plants can be removed only by digging, and should any fragments of the root-stock of couch grass or the root of dandelion be left in the ground, new plants will grow from them. The less deeply rooted weeds may be removed by continuous hoeing, or by hand if they are growing amongst young seedlings. All weeds should be burnt to prevent them from producing seed after they have been removed from the soil. Besides removing weeds, hoeing the ground prevents loss of moisture and cracking of the soil, since large air-spaces are destroyed and evaporation of water is checked. Thus, in a dry soil, hoeing is far more beneficial to plants than soaking them with water.

ROTATION OF CROPS.

It has been found, when growing plants extensively, that the same kind of plant may not grow healthily year after year on the same piece of ground. Different plants require the same mineral salts, but in different proportions. Wheat, for example, makes a heavy demand on the nitrates, so that unless nitrogenous manures be added the amount of nitrate left in the soil is not sufficient for the growth of more wheat. Clover is often grown after wheat, for in its roots live nitrifying bacteria, and when the clover is cut the roots decay and the nitrates pass into the soil. For such reasons it is usual to have a rotation of crops, that is, one kind follows another on one piece of land. Peas, beans, and other deeply rooted plants may be grown after carrots, beet roots, and turnips, the roots of which grow near the surface. Most plants will grow well in soil in which peas and beans have been cultivated. Try to suggest why this should be so.

PRACTICAL WORK

1. Make two seed-boxes by boring holes in the bottoms of small wooden boxes and fitting one side of each with glass. In one, place damp sand, and in the other, damp clay. In each plant a few soaked green peas in such a way that when the roots grow they will be visible through the glass. Make drawings of the root systems when they are well developed, and suggest reasons for any difference you may notice between them.

2. Repeat experiment 1, using loam and peat or leaf mould.

3. Collect plants growing in clay soil by carefully lifting out by the roots one of each kind. Wash the roots gently, taking care not to damage any, and examine the plants. Make notes of the appearance of roots, leaves, and stems, and notice whether the plants possess any features in common.

4. Repeat experiment 3, using plants growing in sandy soil.

5. Make a list of all the differences you can find between the plants found growing in clay soil and those in sandy soil.

6. Make a list of the weeds you find growing in your garden, and in describing each kind note its general habit and the nature of flowers, fruits, and root system. Keep a note of the exact place in which each kind was found.

7. Should any of the same kinds of weeds appear again in the garden, compare the places where they grow with those noted in experiment 6. Make a list of those found in or very close to the same places, and of those appearing in a different part of the garden. Try to associate these differences with the habits of the plants.

8. Plant some green peas thinly in large pots containing loam, and place each under similar conditions favourable to growth. When the seedlings are about two inches high, continue watering one set by pouring water at intervals on to the surface of the soil, and gently fork the surface soil of the others after the same intervals to loosen it. Water the plants by standing them in a pail of water the level of which is about half-way up the pots. Try to account for any differences you may find in the growth of the seedlings.

9. Prepare flower-pots or seed-boxes with loam, and plant in one marrow seeds collected during the autumn, in another seeds collected the previous autumn, in another seeds a year older. Note any difference in the time the seeds take to germinate and in the appearance of the young seedlings.

10. Make a large, clearly labelled drawing of an earthworm to show the shape of the body, segments, reproductive openings, and clitellum.

11. Make a similar drawing to show the shape of the body of the earthworm seen laterally.

QUESTIONS

1. Explain why clay soil is called heavy and cold, whereas sand is light and warm.

2. In which kind of soil, clay or sand, will plants thrive best? Give reasons for your answer.

3. What is meant by loam? How would you make loam?

4. Mention any means by which clay can be improved.

5. Name the ways in which sand may be made less light and warm.

6. Why does lime help to improve the texture of both clay and sand?

7. Is it necessary to manure soil? Give reasons for your answer.

8. What is meant by green manures? How are they obtained?

9. Name any advantages that hoeing has over watering.

10. By what means is water held by the soil? How does the plant absorb soil water?

11. Describe any experiment which shows that soil contains air. How could you find the percentage of air in a sample of soil?

12. Discuss the permeability of sand and clay to air and water.

13. How is the earthworm a useful creature?

14. An earthworm has no limbs, yet it moves along. Describe how it does this.

15. Why is an earthworm said to be diffusely sensitive?

16. What means of protection has an earthworm?

17. If you try to pull an earthworm backwards out of its burrow, you will find it extremely difficult to do so. Why is this?

18. What is meant by weeds? Describe any you have found in your garden.

19. Describe the various ways of getting rid of weeds.

20. What is meant by the rotation of crops? Why should rotation be necessary?

21. Compare budding and grafting as means of propagation of plants.

22. Describe the chief methods of vegetative propagation in plants other than by cuttings, budding, and grafting.

CHAPTER XVI

HOW TO STUDY THE BIOLOGY OF THE SEASONS

SPRING

SPRING is the season of awakening life. Look around you at the plants and animals, and you will realise the truth of this statement. You have read in Chapter X of the ways in which plants and animals store food and prepare for winter. Try to find these living things and examine them to see what has happened to them during the cold months. Look for the emergence of animals which hibernate during the winter, and notice especially the habits of the birds.

The Pigeon

EXTERNAL STRUCTURE AND MOVEMENT.

The pigeon is an interesting bird to study. The wild form, the wood-pigeon, is bluish-grey in colour, with the quill feathers of the wings greyish-brown with a white border. The neck is shot with purple and green. If you keep pigeons as pets, you will be able to handle them and examine them more closely.

Watch the flight of a bird, and notice that the wings are stretched and moved with a downward and an upward stroke alternately. When the wings are stretched almost vertically above the body, the bird, being heavier than air, begins to fall; but the downward stroke, which is much swifter than the other, not only forces the bird forward but also upward. Thus a bird does not fly in a strictly horizontal course, but the wing movements are so rapid that the course appears to be straight.

The feathers of each wing and the skin beneath them are so arranged that they present an unbroken surface to the air when the wings are fully stretched, the wing expanse being concave below and convex above. The under surface of the wing is hollowed in such a way that it curves more steeply towards the anterior end. The less curved part exerts a greater pressure than the other on the air beneath the wing, and so the forward movement is caused. The tail may, like the rudder of a boat, act as a steering organ; it may also be used as a brake. When a bird soars, it takes advantage of the rising air-currents and does not need to use such powerful strokes. The wings are moved chiefly by means of very powerful muscles attached to a projection, the keel of the breast-bone in the mid-ventral line of the thorax. You may realise how well developed these muscles are when you eat the breast of a fowl, for they constitute the whole breast.

The body of the bird is so constructed that it offers little resistance to the air. During flight it makes itself of stream-line shape, so that its passage through the air is as easy as that of a fish through water. The body surface is smooth, for the feathers are directed posteriorly, and the legs may be folded against the body with the feet close to the abdomen, as in the pigeon and all other perching birds, or they may be directed backwards and folded against the tail, as they are in the gulls and herons. The low centre of gravity of the bird is also important when it is in the air, and is due to the fact that the heavy organs, such as digestive organs and keel muscles, are below the lighter ones, the lungs and air-sacs. The wings also are attached high up on the thorax. It is often stated that birds fly against the wind, but there seems to be no foundation for this statement, and it is probable that the air-currents are made use of to help the birds along.

Notice the way in which the feathers are arranged. The wings correspond to the fore-limbs of other animals, that is, the skeleton of each is made up of humerus, radius and ulna, wrist-bones, palm-bones and fingers. You cannot easily distinguish these parts through the feathers, but if you stretch out the wing of a dead bird you will see that the limb-bones are arranged in the form of the letter Z. When at rest, the humerus is directed dorsally and folded close to the body, the radius and ulna are folded against it, but are directed towards the head, and the rest of the limb points towards the tail and slightly towards the ventral surface. The hand possesses only three fingers, and bears along its outer border eleven large flight feathers or quills. The fore arm bears twelve similar feathers along its outer edge, while on the upper arm are a few more. Partly covering these is a layer of shorter feathers, the coverts. The thumb bears a small tuft of feathers. Between the body and the upper arm is stretched a fold of skin, with a similar one between the upper and fore arm. These folds help to form an air-tight surface when the wing is stretched. When the wing is at rest, the feathers overlap each other very much like the sections of a closed and rolled umbrella. The tail has a row of twelve strong feathers arranged to form a fan, and these also overlap each other when the bird is at rest. Most of the remaining part of the body is covered with contour feathers, so called because they determine the shape of the bird and are smaller than the wing or tail quills.

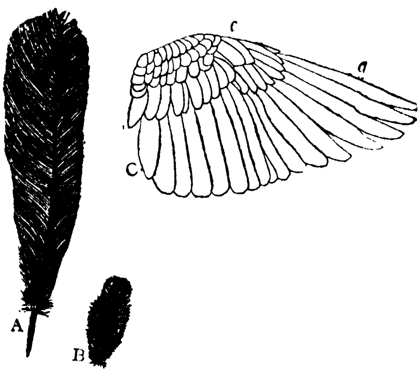


FIG. 91. $\times \frac{1}{3}$.
A. Quill of pigeon.
B. Contour feather of pigeon.
C. Left wing of thrush.
c, Contour feathers; *q*, quill feathers.

If you have ever watched the plucking of a fowl, you will have noticed that the contour feathers do not cover the body surface uniformly, but are arranged in tracts between which are bare areas. The chief areas without feathers in the pigeon are the mid-ventral and mid-dorsal surfaces, while smaller bare tracts occupy the ventral wing surfaces, the ventral surfaces of the legs and the part of the abdomen with which they are in contact, and much of the dorsal leg surface.

The feathers are outgrowths of the epidermis, and correspond to the scales of the snake and other reptiles. Each feather arises as a tiny protuberance, which becomes sunk into a pit, like a house surrounded by a moat. The little knob grows outwards and becomes flattened, while its edges eventually become frayed and so form the vane of the feather. The frayed parts, or barbs, grow out from the central stem of the feather, and each barb bears tiny hooks which interlock with those of its neighbours, so that a continuous expanse of the vane is produced. Between the larger feathers in most birds are found down feathers, which arise in the same way, but in each the stem is short and the barbs remain separate, giving the down a fluffy appearance. The pigeon has no true down feathers, but instead we find on it small hair-like feathers or filoplumes, each with a long stem and a few barbs at its tip.

The feathers not only assist the bird in flight, but also form a protective covering, helping to keep the body warm. The bird is a warm-blooded animal, with a temperature higher than that of any mammal, and since the skin produces no sweat-glands it cannot act as a regulating organ, as it does in mammals, to keep the temperature constant. The feathers closely cover the body, and acting as a blanket, serve to prevent excessive loss of heat from the body surface. The old feathers are shed every year, moulting taking place usually in summer. When the feathers fall, new ones grow to take their place; in some birds these grow so slowly that the bird is practically naked for some time. This happens in ducks and geese, and while the feathers are growing the birds are unable to fly. Some birds moult oftener than once a year, and in these cases the new feathers may be of a different colour from the old ones. Hence we find that some birds have a distinct winter and summer plumage. The colour of the feathers is due partly to colouring matter in the cells of the epidermis and partly to the feather, which is so constructed that the rays of light are reflected in special ways, as in the earthworm. If you hold a peacock's feather to the light, you will find that the colours change according to the position in which you hold it.

The only gland in the skin is on the dorsal surface of the body near the tail, and the secretion of this gland is oil. Watch

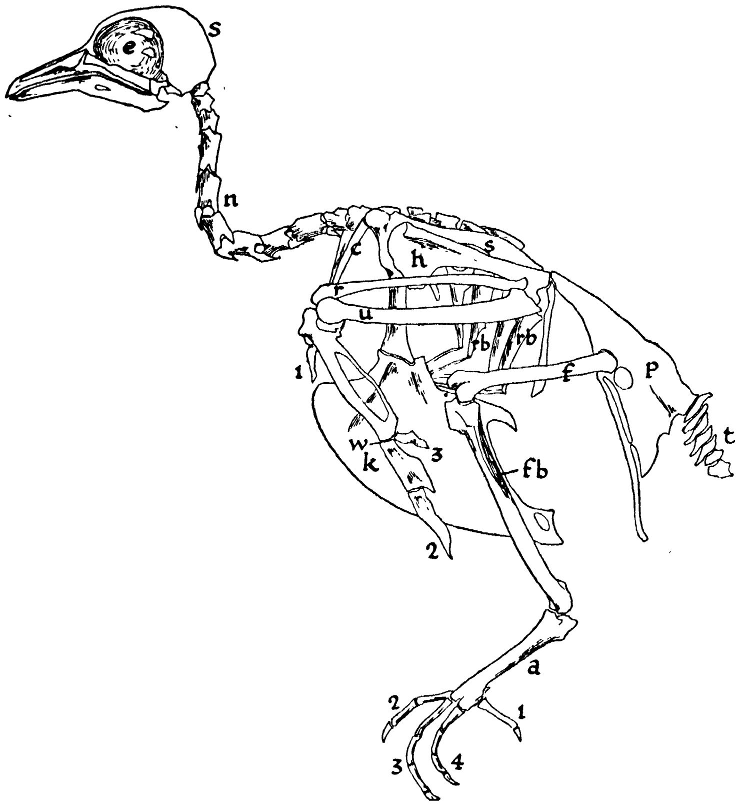


FIG. 92.—SKELETON OF PIGEON SHOWING ONLY LIMB BONES AND RIBS OF THE LEFT SIDE. × ½.

s, Skull; *e*, eye-socket; *n*, neck vertebræ; *t*, tail vertebræ; *k*, keel; *rb*, ribs; *p*, pelvic girdle; *s*, shoulder-blade; *c*, collar bone, *h*, humerus: *r*, radius; *u*, ulna; *w*, wrist and hand; *f*, femur; *fb*, fibula, *a*, ankle and foot The digits are numbered 1, 2, 3, 4.

a bird preening its feathers, and you will see that the beak is pushed in and out between them, so that they brush off the oil which it continually collects from the gland.

The parts of the body not clothed with feathers are covered with scales. These are very similar to reptiles' scales. The hind legs are of the same type as those of reptiles, since there are no free ankle-bones. The thigh-bone is directed towards the head, and the shank-bone towards the tail, while the bones of the sole of the foot are long, and do not lie flat on the ground, so that the ankle is raised some distance above it. The bird thus walks on its toes, which usually number four, and each bears a claw. The first or great toe is directed backwards in the pigeon and most perching birds. The toes and the base of the leg are covered with horny scales.

The pelvic girdle is large, extremely well developed, and affords firm support for the internal organs. If you bend up against the body the hind leg of a newly dead perching bird, you will find that the toes will become curved at the same time. When the bird perches, the bending of the leg at the ankle causes certain of the muscles to stretch slightly, pulling on the tendons, so that the toes are bent. Consequently, the bird never falls off its perch while asleep. The claws of birds, unlike those of the cat, cannot be retracted into a sheath.

Compare the weight of a pigeon with that of a kitten of about the same size. Bulk for bulk the bird is much lighter, because its bones contain a great deal of air and very little marrow. In the pigeon most of the bones contain air-spaces, which are continuations of the air-sacs from the lungs. The bone tissue itself is rather spongy, and the whole skeleton is made in such a way that it gives strength, with as little weight as possible.

Look at the head of the pigeon, and notice the shape of the beak. Are there any teeth in the mouth? The sense of taste is not well developed. The nostrils are almost hidden by a naked fleshy lobe, which acts as an organ of touch. Try to find out whether the pigeon has a sense of smell. The eyes are extremely well developed in birds, so that their sight is very keen. Birds of prey especially have very keen sight, as you will discover if you have the opportunity to watch any kind of hawk. Each eye is provided with three lids, the third serving, like that of the frog, to keep the eye clean. Notice how frequently this lid is flicked across from the inner corner of the eye, especially in a parrot, where it moves rather slowly and suggests the action of winking. The ears are situated just below and posterior to the eyes, the openings being usually concealed by the feathers. In each ear the drum membrane is stretched across the tube a little way in from the opening. If you have ever tried to watch the habits of wild birds, you will realise how acute is the sense of hearing.

Feeding and Digestion.

The pigeon, like many other birds, feeds on seeds, which are picked up by the sharp, pointed beak. As there are no teeth, the seeds are not ground up in the mouth, but are swallowed with the saliva into the gullet. Perhaps you have looked at the inside of a chicken, and have wondered at the collection of stones and grit as well as of unaltered corn in the crop. This thin-walled outgrowth from the gullet acts as a storehouse for food, so that a bird can eat more than is necessary at a meal, and digest it while resting. The food passes on into the two-chambered stomach, the posterior chamber being the thick-walled gizzard. The lining of the gizzard is thrown into hard and horny folds, and by means of them, with the assistance of the stones and grit swallowed by the pigeon, the food is crushed and ground ready for further digestion. This habit of swallowing stones and other hard fragments is well marked in the ostrich, whose powers of digestion have thereby become a byword. When the food has been digested and absorption has taken place, waste is expelled through the anus, opening into the cloaca, which is found on the ventral surface at the posterior end of the body.

Breathing.

When the bird breathes, air passes through the long trachea, which is surrounded by complete bony rings. At the base of the neck it branches into two bronchi, as in the cat. The lungs, however, are spongy organs which do not project into the cavity of the thorax, but are fixed firmly against the ribs, so that they cannot contract and expand like the cat's lungs. From them grow out nine thin-walled, bladder-like organs, the air-sacs, which help to fill the spaces between the internal organs, and some of which are in connection with the air-spaces in the bones. When the muscles between the ribs are relaxed, the air-sacs are expanded and full of air. In contracting, these muscles pull the ribs backwards, causing the chest cavity to become smaller, so that the air-sacs are compressed and the air forced out. The muscles then relax, and the air-sacs expand again. The air-sacs always contain some air, and, unlike the lungs, are not supplied with numerous blood capillaries for the extraction of oxygen from the air. Thus when air is breathed in, it rushes through the lungs into the sacs, and the blood in the lungs extracts oxygen as the air enters, and also as it passes out. The oxidation of food materials to produce energy is very great, and this accounts for the great activity and high temperature of the bird's body. The large air reserves may be partly responsible for the powers of endurance exhibited by birds on the wing.

The larynx is situated at the top of the trachea, but does not appear to be of much use. At the junction of the bronchi, that is, at the base of the trachea, is a much more complicated voice organ, the syrinx, in which is a valve which vibrates when air is forced violently through it, and in this way the bird's song is produced. By means of muscles attached to the syrinx, the rate of the vibrations may be varied. If you open the top of your piano and watch the strings vibrate when you strike the notes, you can see that the strings attached to the low notes vibrate much more slowly than those attached to the high notes. In the same way the low notes in a bird's song are produced when the valve in the syrinx vibrates slowly, and high ones when it vibrates rapidly.

Reproduction.

Spring is the season when birds begin nest-building. Migrant birds returning from warmer countries have been known to choose for nest-building the site that they occupied during the previous spring. The wood-pigeon makes its nest of twigs so loosely interwoven that it merely forms a platform in the branches of a tree, and the two white glossy eggs may often be seen through it from below. Some birds build in trees, others in bushes; some, like the house-martin, choose the eaves of a house, while a few, such as the partridge, simply scrape a hole in the ground and lay the eggs therein. When you are looking for birds' nests, take care not to disturb their inhabitants more than is necessary. Always note the place in which the nest is found, the materials of which it is built, its shape and texture; whether it be lined with down feathers stripped from the parent's body; the number, colour, and shape of the eggs, and the appearance of the young. With practice you may be able to watch the parents feeding the young, and discover how often they are fed, whether one or both parents go in search of food, and of what the food consists. If you are making a hobby of egg-collecting, take only one egg from a nest containing several, and do not collect more than one egg of its kind. Make a pin-hole in each end of the egg, and blow or suck out the contents. Keep the eggs each in a nest of cotton wool in a box, and write the name of the bird on a slip of paper and gum it on the lid to mark the position of the egg.

Listen for the songs of the birds. You may be able to see the songster and to find out its name. Listen carefully to the notes, and try to discover whether the same note is constantly repeated, as in the call of the starling, or whether different notes are sung, forming a melody. Some birds, like the thrush, repeat a phrase of four or five notes, while the cuckoo, as you know, has only two notes, which it seems never to tire of uttering.

Try to watch one nest, so that you can note the time between egg laying and hatching, and whether the young birds are naked or covered with down. Watch very quietly near the nest, but under cover, so that you are not visible to the birds. You may be able to see the young ones learning to fly, and find out at what age they leave the nest. Many birds have two or three broods of young in one season; the wood-pigeon usually has three.

OTHER ANIMALS.

Look for animals awakening from their winter sleep. If you can go into the country, note the first day you see a frog or a toad, and keep a record of the weather on that day. On a fine evening go out and listen for the croaking of frogs around a pond. Look for frogs' spawn, and keep a record of the date of your discovery and the kind of weather on that day. In the same way keep records of the habits of toads and newts. It is a good plan to study one particular place, such as a pond, field, wood, or tract of seashore, and keep a record of the plant and animal life you find there in the spring.

Look especially for young animals, for spring is the season when many young are born. Watch the lambs, the kittens, and the puppies. Notice whether the parents join in the play. Listen for the calls of animals, the bleating of lambs and the lowing of calves, and note whether the parents respond.

In the ponds you will find sticklebacks and various insects, so that this season is very suitable for starting an aquarium.

PLANTS.

Observe the trees carefully, and note the first kinds to open their buds. Look for tree flowers, and see if you can find some on every tree. Why are so many tree flowers difficult to find?

When making a collection of wild flowers, pick only one, or not more than two, of each species of flower you wish to keep. To preserve the flower, place it between folds of tissue-paper, taking care to press out petals and other leaves, so that they lie as flat as possible. Large-headed flowers, like thistles, cannot be pressed successfully. Lay the tissue-paper between pads of cotton wool, and place this between sheets of cardboard, keeping the press together with an elastic band. Hang the press in a warm, airy place, examine the specimens each day and replace damp paper by dry pieces. To preserve the colour, flowers should be dried as quickly as possible. The press may even be hung near the fire or out of doors in the sun. If you cannot use this method, place the tissue-paper with its contents under some heavy books until the flowers are dried, when they are ready for mounting. A drawing-book will serve for this purpose. The flowers may be lightly covered with gum and pressed down firmly on the paper, or very narrow strips of gummed paper may be fastened across the stems and stalks. Always make the mounting as neat as possible. By the side of each flower print neatly its name, the date on which it was found, the place where found, and any other interesting facts about it.

Spring is also the season of seed-sowing, when window-boxes may be replanted, and seeds must be sown in seed boxes and pans ready for the garden later on.

SUMMER

Summer is the season of the abundance of life, when animals and plants are most active. Continue to watch the birds you observed in spring, and notice the progress of the young ones. Find out whether the notes of the birds change. Watch for the departure and return of migrants, keeping a record of the earliest departures of those which arrived in spring.

Insect life is abundant in summer, and you may be able to collect specimens for observation and rearing in insect cages, and also to watch the habits of the insects, both when they are free and in captivity.

Continue the collection of flowers you started in spring. Compare the colours of spring and summer flowers, and find whether there is any general colour scheme for each season. Watch the visits of insects to the flowers, and keep a record of the types of flowers visited by long- and by short-tongued insects. Try to discover in each case what attracts the insects. Watch the ants in woods or gardens, and try the special methods of observation suggested in Chapter VIII. Try to find where wasps nest, by watching them carefully when they hover about banks and roadsides, or crawl about on the surface of the ground. If you know where beehives are kept, try to get permission to visit them and study the habits of the bees.

CLIMBING PLANTS.

Examine the plants in the hedgerows, and notice, especially on the shady side of the hedge, how many of them reach the top by attaching themselves by some means or other to a support. These climbing plants have stems which would grow erect, but the amount of woody tissue produced in them is so small that they bend under their own weight, and if left unsupported would trail along the ground with only the growing tip directed upwards. Why do they not continue to scramble over the surface of the soil, instead of finding some support to help them to climb? If they remained at the foot of the hedge, their green parts would not get sufficient light, the flowers would be hidden by other plants, and the fruits or seeds would not easily be dispersed. It is therefore to their advantage to be able to cling to some support, and in order to do this many are furnished with prickles. Examine the prickles on the dog-rose and blackberry, and suggest why their points are all directed downwards away from the growing tip of the stem. The prickles on these plants are outgrowths from the stem comparable to hairs, while in the goose-grass they are hooked hairs. Notice that when the blackberry produces suckers, the hooks are reversed on the part of the stem that bent over from the parent plant. Why is this?

Other plants climb by means of tendrils, long, green threads, which may be formed from leaflets, as in the sweet-pea; from leaves, in the meadow vetchling; or from branches, in the white bryony. Try to discover why, in each case, the tendrils are said to be formed from the parts mentioned. In a young plant the tendril is straight, and should it not reach a support it will eventually die. When it touches a support, the side in contact grows much more slowly than the opposite side, so that the tendril becomes curved round the support. This curvature is continued, and the part of the tendril which is still straight coils too; but since the base of it is fixed, it can coil only in the opposite direction to that part turned round the support. This double spiral is well marked in the tendrils of the white bryony, and you can test their elasticity and strength by gently pulling the stem away from the support. Gently stroke with a pencil the under surface of a young, straight tendril of this plant, and you may be able to induce it to coil, even though you remove the pencil. The tendrils of the self-clinging Virginian creeper do not coil, but when their tips come into contact with a rough surface they stick to it, and then swell out to form little discs. You may see these discs filling tiny holes in the bricks of a wall. In plants such as the nasturtium and clematis the petioles act as tendrils, but usually make only one or two coils round the support.

Stems also may climb, and where this happens, as in the hop, the internodes at the tip are very short, and the leaves quite small, so that they do not get injured as the stem twines round its support, and the internodes lengthen rapidly as this takes place. If you look at the tip of a climbing stem, you will find that some stems always twine to the right, that is, they follow the direction of the hands of a clock, while others twine to the left, in an anti-clockwise direction. Examples of the former are the honeysuckle and hop, while the convolvulus and runner bean twine in the opposite direction.

The ivy does not climb by any of the means described. Pull a spray from the tree trunk or other surface to which it clings, and notice that it is attached by means of short, brown, thread-like organs densely clustered together. These are adventitious roots.

Most climbing plants grow very rapidly, as you will discover if you keep a record of the growth of hedgerow plants. Can you suggest a reason for this rapid growth?

True Fruits.

Towards the end of summer start a collection of the ripe fruits of plants. You will find that the ovary wall or pericarp of many fruits, such as those of the wallflower, becomes dry and skin-like when ripe, while that of others, such as the gooseberry and tomato, remains fleshy. Notice whether the fruit has one seed or many, and whether each flower produces one fruit (a simple fruit) or several fruits (a compound fruit). The object of seed-formation is the production of new plants, and in order that the seeds may reach the soil and there germinate, many fruits open in some way to let them out. Such fruits are said to be dehiscent, and those which do not open are indehiscent. There are several types of dehiscent fruits. Look at laburnum pods, and notice that each splits into two parts, and perhaps along one edge of each part you will see a few seeds still attached. This type of fruit, characteristic of all plants of the Pea family, is formed of one carpel, is dry and dehiscent, splitting along both margin and midrib. It is described as a pod or legume. Very similar to it is the fruit of the columbine or peony, but here each simple fruit splits along the margin only. Such a fruit is called a follicle. The dry, dehiscent fruit of the wallflower is formed by the union of two carpels, which separate from the base upwards, leaving the seeds attached to a thin partition which is not the true placenta, but is a false membrane between the carpels. This fruit is a siliqua, and differing from it only in shape and size is the little siliqua or silicula of the shepherd's purse. All dehiscent fruits formed by the union of carpels are called capsules, and the siliqua and silicula are special kinds of capsules. The majority are dry fruits, but the horse-chestnut capsule is an example of a fleshy one. Capsules may dehisce

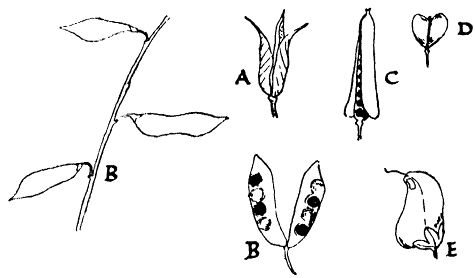


FIG. 93.—DEHISCENT FRUITS.

A. Follicles of columbine.
B. Pods of broom (one open to show seeds).
C. Siliqua of wallflower.
D. Silicula of shepherd's purse.
(A–D) × ½.
E. Capsule of snapdragon. × 1.

in various ways. The willow-herb opens from top to bottom by the separation of the carpels. Those of the primrose separate only at the top and curl back; the pimpernel capsule opens by means of a lid, whereas other capsules, such as that of the poppy, have definite pores. Collect and examine examples of legumes, follicles, siliquas, siliculas, and capsules, and notice that all contain many seeds. One-seeded dry fruits do not usually dehisce, and perhaps you can suggest a reason for this. The chief types of indehiscent dry fruits are the nut and the achene, which may be formed of any number of carpels, the only difference between the two fruits being that a nut has

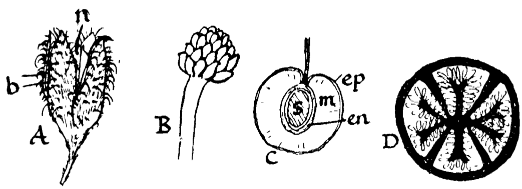


FIG. 94.—INDEHISCENT FRUITS

Dry { A. Beech-nut. *n*, nut; *b*, bract. × ½.
B. Achenes of buttercup. × 1½.

Fleshy { C. Longitudinal section of cherry (drupe). *ep*, epicarp; *m*, mesocarp; *en*, endocarp; *s*, stone. × ½.
D. Transverse section of tomato. × ½.

a woody pericarp which is much tougher than that of the achene. The buttercup fruit is compound, and consists of a collection of achenes; the acorn is a nut partly enclosed in a cup formed by the bracts.

There are two kinds of fleshy fruits, both of which are indehiscent. The pericarp of the berry is entirely fleshy, while the innermost layer of the pericarp of the drupe is hard and stony. Examine a gooseberry, and notice the two layers of the pericarp, the fleshy mesocarp and the outer skin, or epicarp; the "pips" are the seeds. In a plum you will find that these two layers of the pericarp surround the stone, the shell of which is the endocarp, the innermost layer of the ovary wall, while the kernel is the seed. All so-called stone fruits are drupes, while the blackberry and raspberry are compound fruits, consisting of numerous tiny drupes or drupels. Berries are usually many seeded, and include such fruits as the grape, cucumber, tomato, vegetable marrow, banana, and currant. A one-seeded berry is seen in the date, where the hard stone is the endosperm of the seed.

DISPERSAL OF FRUITS.

Indehiscent fruits may be scattered by various means. The wind distributes the winged fruits of such plants as sycamore and ash, and the plumed fruits of dandelion, clematis, and

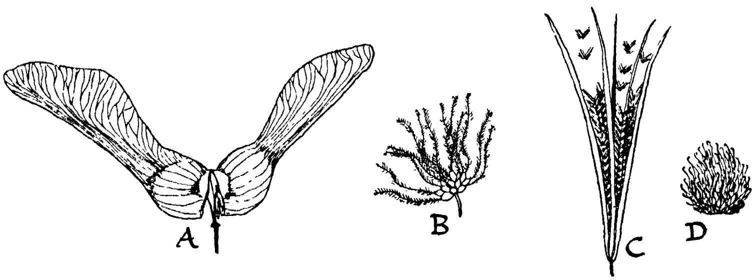
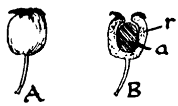


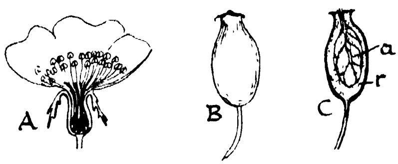
FIG. 95.—FRUITS DISPERSED BY WIND.

A. Sycamore—winged fruits. × ½. B. Clematis—plumed fruits. } × ½.
C. Willow-herb—plumed seeds. × 1. D. Burdock—hooked fruit (burr). }

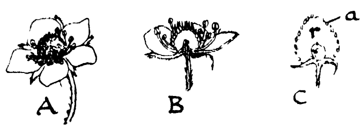
other plants in which the fruits are provided with silky hairs acting as parachutes. You may have provided the wind when you tried to tell the time by a dandelion "clock". Thistledown floating in the air is a very common sight. The willow-herb fruit contains plumed seeds which are blown away when the capsule dehisces. Animals help to scatter seeds when they eat the fleshy parts of fruits and throw away the seeds. Think of the number of apple pips you have scattered in this way. Often the animal eats the whole fruit and its contents, but the seeds pass unharmed through the digestive organs and eventually are excreted. Many fruits bear hooks which catch in the coats of passing animals and are rubbed off and distributed. You may often have collected "burrs" on your stockings and carried them to other places. The fruits of water plants may be shed into the water and be carried away by the current and washed up elsewhere. The coconut palm scatters its fruits in this way.



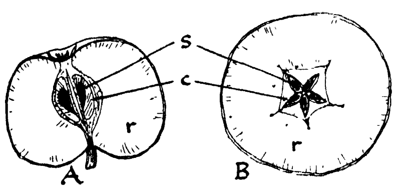
HAWTHORN. × ½.
A. Fruit. B. Half fruit.
r, Receptacle; *a*, achene.



ROSE. × ½.
A. Half flower. B. Fruit.
C. Half fruit.
r, Receptacle; *a*, achene.



WILD STRAWBERRY. × 1.
A. Flower. B. Half flower.
C. Half fruit.
r, Receptacle; *a*, achene.



FRUIT OF APPLE. × ½.
A. Longitudinal section.
B. Transverse section.
s, Seed; *c*, core or ovary wall; *r*, fleshy receptacle.

FIG. 96.—FALSE FRUITS.

FALSE FRUITS.

The juicy part of the apple is not part of the true fruit at all, but has been formed by the receptacle of the flower surrounding the ovary and becoming large and fleshy. The core is the true fruit, the tough skin being the pericarp and the "pips" the seeds. When a fruit is not formed from the ovary alone, but from other parts of the flower as well, it is known as a false fruit. Apples and pears are false fruits formed in a similar way from perigynous flowers. Other false fruits are hips and haws. In these the brightly coloured fleshy envelope has been formed from the flask-shaped receptacle containing the hard fruits, each of which is an achene. The true fruits in the strawberry are tiny achenes too, while the juicy part on which they are borne is the much enlarged receptacle. In the mulberry, a compound fruit, the fleshy part of each simple fruit is formed by the perianth. The fig is peculiar in that the whole inflorescence helps to form the fruit. The receptacle bearing the flowers becomes curved so much that they are practically closed in, and as the fruits ripen the rest of the inflorescence becomes fleshy. Thus the edible part of the fig has been formed from receptacle and inflorescence, while the "seeds" are really true fruits, each of which is a tiny nut.

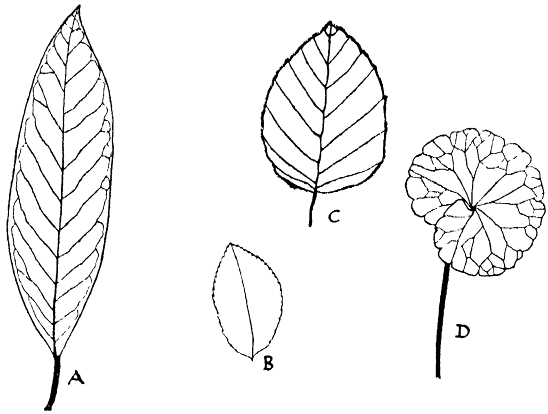
NUTS.

Strictly speaking, many so-called nuts are not true nuts. The walnut, almond, and coconut, for instance, represent the "stones" of drupes, the shell being the endocarp, the mesocarp and epicarp having been removed. The epicarp and mesocarp of the walnut and almond are green and somewhat juicy, while those of the coconut constitute the fibres used to make coco-matting. The pea-nut or monkey-nut is really a legume, the pericarp of which has become woody. When the fruits are ripening, each peduncle bends over until the fruit touches the ground, in which it becomes embedded, and so the seeds are planted in a unique way.

Remember when collecting fruits that many of the brightly coloured berries are poisonous to human beings, and so should not be eaten by them.

AUTUMN

Since autumn is the season of fruition, you will be able to continue collecting fruits during this season. It is often called the "fall" of the year, and you will no doubt be able to suggest the reasons for this title. How do the leaves get their beautiful colours? The colour change is probably due to the action of enzymes affecting the cell sap. The flow of the sap in trees is not as vigorous as in the spring, when the buds begin to burst, requiring a plentiful food supply, and growth is active. Thus in autumn the amount of surface needed for transpiration is not so great, and a callus of corky cells forms across the base of each leaf-stalk. As this prevents the passage of liquid between stem and leaf, not only is transpiration checked, but the food supply of the plant is decreased, and the leaves fall from the tree, their position on the twig being marked by the corky callus, which forms a scar.



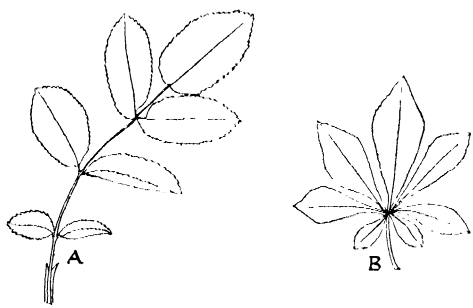
SIMPLE LEAVES. $\times \frac{1}{2}$.

A. Laurel—
Margin entire.
Venation pinnate.

B. Rose leaflet—
Margin serrate.

C. Beech—
Margin ciliate.

D. Ground ivy—
Margin crenate.
Venation palmate.



COMPOUND LEAVES.

A. Rose— $\times \frac{1}{2}$.
Pinnately compound.

B. Horse-chestnut— $\times \frac{1}{4}$.
Palmately compound.

FIG. 97.

LEAVES.

Collect as many different kinds of leaves as you can, and separate them into types. Distinguish between simple leaves and compound leaves. Notice carefully the arrangement of the veins in each leaf. They show much more prominently on the back of net-veined leaves, in some of which there is one chief vein with others branching from it. Such an arrangement is said to be pinnate (L. *pinna*, a feather), and is found in lilac, beech, and elm. In other leaves you will notice that there are several chief veins, which may radiate from one point as the fingers do from the palm. Leaves of sycamore, plane, and nasturtium show this type of venation, which is described as palmate.

Make labelled drawings of each leaf to show its shape and its venation. The apex of the leaf may be sharply pointed, blunt, or rounded. The leaf margin may be entire, as in lilac. When it is fringed with hairs, as in the beech, it is ciliate. The rose-leaf margin is cut up into very fine teeth, and described as serrate (L. *serra*, a saw). Leaves with larger, more irregular teeth are dentate (L. *dens*, tooth). This type of leaf-edge is seen in the Virginian creeper. The leaf-margin in the ground-ivy is cut up into small rounded lobes, and is said to be crenate (L. *crena*, a notch). Distinguish carefully between simple leaves, such as those of the buttercup, with a much divided lamina, and compound leaves, where the incisions reach right to the mid-rib, so that several leaflets are formed. A compound leaf may be distinguished from a branch bearing simple leaves by the fact that the branch ends in a growing point and bears buds in the axils of the leaves, while the compound leaf bears no buds either at the tip or in the axils of the leaflets.

THE SPIDER.

Autumn is the season of the year when the spider is most active, and may be seen building its web, or lying in wait for the flies, which are becoming sluggish in their habits. Try to watch a spider spinning. In the case of the large garden spider the female weaves the web. She begins by spinning a long thread, which may float on the breeze until it touches and becomes fixed to some firm support; or she may fix the end of the thread to a support and climb to another position, paying out the thread as she goes, and, by means of her legs, preventing it from touching other objects until she reaches the new position, where she fixes it firmly. By one means or the other she makes a framework of silk, then she climbs to the uppermost part, in the middle of which she fixes a new thread, and then proceeds to drop to the lowest level of the web, again paying out the silk as she goes. When the new thread is fixed at the lower end she has made a diameter, up which she climbs till she reaches the middle point, where she begins another radius, carrying the thread with her up the first radius to the foundation line at the top, along which she walks a short distance, and then fixes the thread. Returning to the centre, she spins another thread and fixes it to the framework, and in this way the spokes of the web are made. The spiral thread is also begun at the centre, and is attached to each spoke as the spider passes over it. Often, towards the outside of the web, it is necessary for the spider to run up one spoke towards the centre and back along the next one in order to get across the wide space between them. This first spiral is not sticky, and the turns of it are fairly wide apart. A second one is begun from the outside, and the thread used is covered with a sticky fluid which, with the help of a strong lens, may be seen adhering in drops to the silk. The turns of this spiral are much closer together, and as she fixes it the spider bites away the first one. When she has finished she may wait patiently, head downwards, in the centre, or she may climb to a hiding-place amongst the leaves of the bush or tree, and

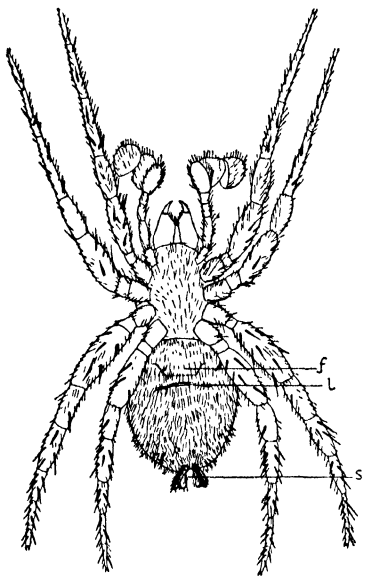


FIG. 98.—SPIDER (ENLARGED), VENTRAL SURFACE.

s, Spinnerets; *l*, lungbook; *f*, flap covering openings of reproductive organs.

attach herself to the web by a silken thread. The slightest vibration of the web affects the thread, down which the spider climbs to investigate the cause of the disturbance. If it be due to an insect having become ensnared, she paralyses it by biting it with her poisonous fangs, and sucks out the body contents. Sometimes she may carry it away to be consumed later. Before the spider attacks it for food, a larger or dangerous insect, such as a wasp, is first bound with silk to prevent it from struggling.

Where does the silk produced by the spider come from? Look at the ventral surface of the tip of the abdomen in the large garden spider, and with the help of a lens you will be able to see the six tiny spinnerets, in which are numerous holes through which the silk flows. The holes are the openings of the silk glands secreting a gummy liquid which hardens as it escapes, and the strands of silk produced join together to make one thread as they leave the body.

You can distinguish the large garden spider by its size and colour, the body being brown or grey, marked with white spots and lines, some of which are arranged in the form of a cross on the dorsal surface. The ventral surface is darker than the dorsal surface, but as the spider often hangs upside down from a horizontal web this coloration is as much a protection as that of a cat or fish. The body, unlike that of an insect, is divided into two parts only, there being no division between the head and thorax. There are six pairs of appendages, all arising from the head-thorax region. Each of the first pair has two joints, the base and the fang, and the latter is hollowed into a tube through which poison flows from poison glands in the base. When not in use, the pointed curved fang can be closed against the base, like the blade of a penknife. On either side of the mouth is a six-jointed appendage, which may serve the purpose of an antenna. The basal joints of these appendages are hard, and serve to squeeze the juice from the bodies of insects into the mouth of the spider. You have probably noticed that the spider does not eat solid food, but leaves the empty carcases of its victims on its web. The other appendages are the four pairs of walking-legs. Each is long and hairy, and ends in two or three curved claws.

How does a spider breathe? If you look on the ventral surface of the abdomen near to its junction with the head-thorax, you will see, with the help of a very strong lens, a tiny flap covering the openings of the reproductive organs. On either side of this is a narrow slit, the opening of the respiratory cavity containing the breathing organs or lung-books. These consist of numerous thin plates projecting into the cavity and arranged like the leaves of a book. Each plate contains blood, and as air flows between them it passes through the thin walls into the plates, and oxygen is extracted from it. In addition, there are breathing tubes leading into two stigmata situated near the spinnerets. The anus is found on the ventral surface slightly posterior to the spinnerets. On the head are eight simple eyes.

Towards the end of autumn the garden spider lays several hundred eggs and weaves around them a cocoon of yellow silk. This she places in a sheltered position, such as a crack in the bark of a tree, where it may remain until the following spring. The young spiders emerging from the eggs are exactly like their parents in appearance, and they go floating away through the air on long silken threads known as gossamer. You may sometimes see them doing this in the autumn. As they grow, their outer, tough skin does not grow with them, so that it is shed frequently, there being as many as eight moults in the first year. When they are mature, the females may be distinguished by their size, being in some cases five or six times larger than the male. His insignificance may be a protection, for the female is very ferocious, and is quite capable of killing and devouring him should she not desire his company.

Migrant Birds.

Animals that store food for the winter are very busy in autumn, and if you search in holes and cracks in tree-trunks you may discover the squirrel's store. Many kinds of birds are preparing for their long flight, and you may see swallows collecting together in flocks, perhaps on telegraph-wires and other supports. Birds cannot store food, as many animals can, but they have one advantage, the power of flight, enabling them to leave the area where food is scarce for one where it is more abundant. Nearly all birds migrate, although many may move their quarters merely to another county, or even to a place but a few miles away. Birds which do not travel very far are known as permanent residents, and in Great Britain the commonest of these are the robin and thrush. Others, like the swallow, are summer residents, who spend the winter in warmer countries. The field-fare is one of the winter residents, coming to us in the autumn and leaving in the spring for places farther North. Birds travelling a great distance usually fly very high and at great speed, taking advantage of the air-currents to help them along. A bird flying at twenty miles per hour with a wind blowing at ten miles per hour would cover three hundred miles in ten hours, whereas a bird travelling at the same rate in the opposite direction would take thirty hours to cover the same distance. It is often stated that birds fly best against the wind, and that they cannot fly with the wind, since it ruffles their feathers. The ruffling of the feathers would alter the smooth surface of the birds and so hinder their progress, but as their speed is greater than that of ordinary air-currents, birds can fly with the wind without the feathers being affected. When the wind is very strong, birds find it difficult to fly at all. Also, since migrating birds fly very high, those that *are* seen flying against the wind are probably doing so because it is preventing them from reaching higher levels.

How do birds find their way to other places, especially in their first year, when they have not before flown far from the nest? Many of them follow coastlines or river valleys, probably because it is in these places that most food can be found on the journey. When crossing the sea, possibly hundreds of them lose their way and so perish. Some are attracted by the light in lighthouses, and crash against the glass with such force that they fall stunned and are dashed against the rocks below. In some lighthouses perching-rails and a platform have been erected around the lantern to prevent the birds from being killed.

Summer residents in Great Britain always migrate southwards in the autumn, but return in the spring for nest-building and breeding. How do they find their way back? They have extremely good sight, but this is not of much advantage to them when they fly so high. Their brain is very well developed, and possibly they have good memories. Much more important in this respect, however, is their strong homing instinct. You doubtless know how well developed this instinct is in pigeons, so that they can be used for the purpose of carrying messages from one place to another. The homing instinct is well marked in cats; one carried in a closed basket to a farm two miles rom its home found its way back again across the fields. Connected with the homing instinct is that of reproduction, and all these influences may affect the bird, and cause it to return to its other home in the spring.

In the autumn you may examine birds' nests, since most of their owners have deserted them. Notice of what each nest is made, and see if you can discover where the builder found the materials. Compare the shapes of the nests with the shapes of the birds that lived in them.

WINTER

BUDS.

Winter is the season of sleep, when the majority of plants and animals are more or less inactive. Trees have lost their leaves, and the new leaves are still hidden within the buds. Do all buds contain leaves, and what are the leaves like at this stage? We must open a bud to discover this, and since most tree buds are rather small, it is better to examine a large bud, such as a brussels sprout. Looked at from the outside it seems to consist of numerous leaves arranged one over the other and partly overlapping. Cut the bud in two lengthwise through the middle, and inside you will see a solid, compact structure, wide at the base and tapering to a point at the top. This is the stem, and the tip of it is the growing point, which is protected by the closely packed leaves. Notice that these decrease in size towards the tip, where they are extremely small, and are crowded together because the axis between them is so short. The part of the stem between two leaves is described as an internode, and that from which a leaf arises is the node. In the axils of many of the leaves of the brussels sprout you will see a bud. Thus the structure of the whole sprout shows that it is an undeveloped shoot, and similarly every bud is an undeveloped shoot.

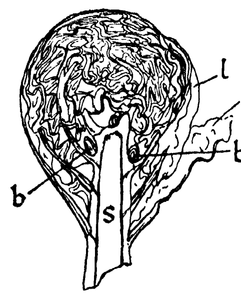


FIG. 99.—SECTION OF BRUSSELS SPROUT. × ½. *s*, Stem; *l*, leaf; *b*, axillary bud.

The young tender shoots of most trees remain undeveloped during winter, and so are provided with tough outer coverings for protection against frost. The covering leaves also prevent much transpiration from taking place, a necessary precaution when the plant is not very active. Notice that further protection is provided for the horse-chestnut bud by a sticky fluid secreted by the leaf cells and covering the outer surface of the bud. If you strip off the leaves one by one, and arrange them in order as you remove them, you will find that they become smaller and less sticky, and that the inner ones are covered with silky hairs forming a kind of down. A change in shape may also be seen, until you reach leaves shaped like the ordinary foliage leaves, but very much folded. The outer, or scale leaves, are foliage leaves, or parts of foliage leaves modified for protective purposes, and are shed as the bud develops. In the middle of the bud you may find a very young inflorescence.

Look at a twig of horse-chestnut and examine the leaf scars, the shape of which has suggested the name of the plant; but it is also said that the fruits were used as a medicine for horses.

Each scar marks the position of a fallen leaf. What do the "nails" represent? Notice the position of the scars with reference to the buds, and also count the ring-shaped scars and find the age of the twig.[1]

On the surface of the twig may be seen numerous lighter-coloured raised patches, the lenticels, and they appear more prominent in winter because they have become partly or wholly blocked with corky cells. Can you suggest why they are blocked?

At the tip of the stem is the terminal bud. Buds arising below it on the same branch are lateral or axillary buds. Many of these may be very small and are said to be dormant, since normally they do not develop with others formed at the same time. As their name suggests, they are sleeping buds and not dead ones, for should any of the buds above them be injured, the dormant ones may develop and produce new shoots. This development is taken advantage of in the process known as pruning, when certain buds are removed from a plant in order to induce others to develop.

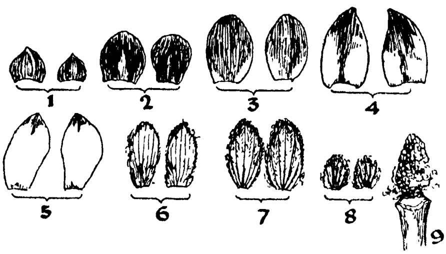


FIG. 100.—HORSE CHESTNUT BUD. × ½.

In the first five pairs of scale leaves brown parts are shaded, green parts left white. The next three pairs are foliage leaves—green. No. 9 shows the inflorescence.

On the twigs of some trees you will notice that only one bud arises at a node. This arrangement of buds on a stem is described as alternate. On others, two buds are found at a node, and often the arrangement is such that one pair grows at right angles to the next pair. This is described as opposite and decussate. Should all the buds develop and produce shoots of equal length, trees would be very symmetrical in shape. We do not find that this happens, for many buds remain dormant, and development takes place unevenly. Thus the

[1] Chapter V, p. 112.

shape of a tree depends not only on the arrangement of its buds, but also on their development. It is, therefore, quite easy to distinguish most trees in winter by their shapes, by their bark, and, since no two trees produce buds exactly similar in appearance, by their buds. The following descriptions will help you to distinguish a few trees:—

(*a*) Horse-chestnut twigs are stout, with smooth, brown bark. The internodes are fairly long and straight.

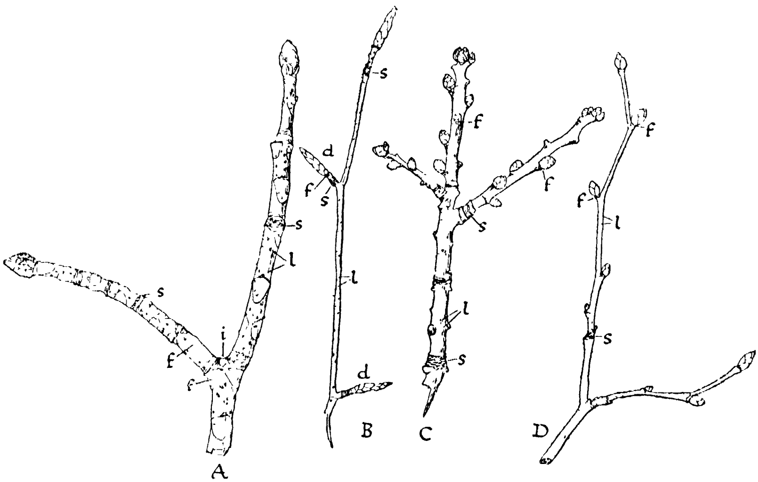


FIG. 101.—TREE TWIGS IN WINTER. × ⅓.
A. Horse-chestnut. B. Beech. C. Oak. D. Elm
f, Foliage leaf scars; *s*, scale leaf scars; *i*, inflorescence scar; *l*, lenticels; *d*, dwarf branches.

Leaf and scale scars are well marked. The buds are large, pointed, reddish-brown in colour, and are covered with a sticky secretion. They are arranged in pairs.

(*b*) The ash has greenish-grey, rather smooth bark, and such dark olive green buds that they appear to be black. The terminal bud, if held in an inverted position, may suggest the shape of a deer's foot. Axillary buds are opposite and decussate, and the stem is broad and flattened at the nodes. The internodes are usually long and the stem is rather straight.

(*c*) The oak may be distinguished by its bent and often

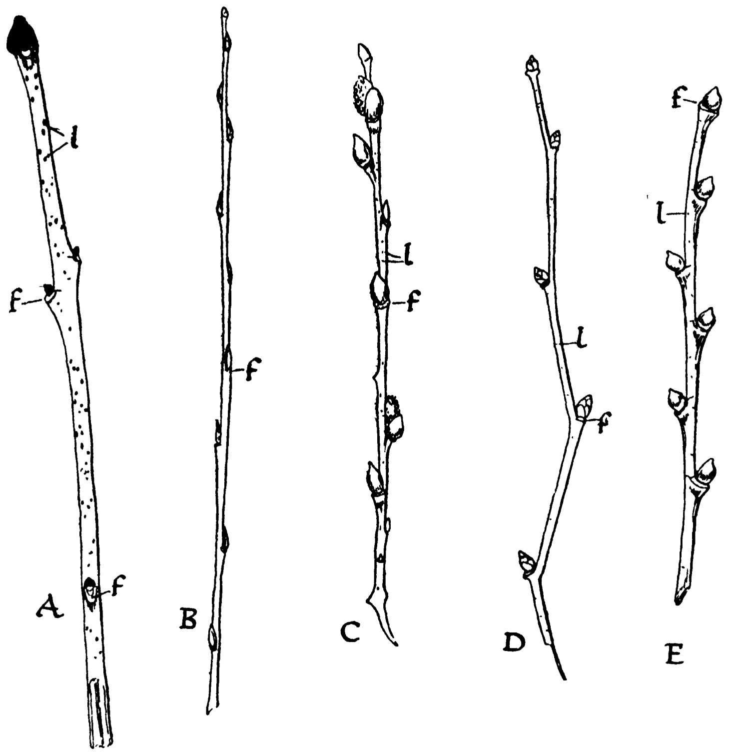


FIG. 102.—TREE TWIGS IN WINTER × ½.

A. Ash. B. Willow. C. Willow, showing foliage and flower buds. D. Hazel. E. Plane.

f, Foliage leaf scars; *l*, lenticels.

twisted twigs with their very short internodes, those between the terminal bud and the buds immediately below being very short indeed, so that there appears to be a cluster of buds at the tip. The bark is rough and brown, and the buds somewhat lighter in colour;

they are rounded in shape, and each is situated on a large bud "cushion", so that the nodes project like rheumatic finger-joints.

(*d*) Elm twigs are slender and grey-brown in colour, and the buds are reddish-brown and small. The stem is not very straight, but makes a slight bend at each node. The bark of the trunk is rough, dark grey, and very furrowed.

(*e*) Beech buds are long, slender, and pointed. They arise alternately on the reddish-brown twig, and between them are long internodes. In many cases the bud terminates a very short branch with well-marked scale-leaf scars at its base. Beech bark is light grey, very smooth, and peels off in large thin flakes.

(*f*) The buds of the plane-tree are short, thick, and pointed, and each appears to be entirely covered by one bright brown scale leaf. The twigs are brown, smooth, and slightly bent, and the nodes are much swollen, so that each bud arises on a well-pronounced cushion. The grey bark peels off in thin flakes, disclosing fresh green areas which soon become grey.

(*g*) Willow twigs are reddish-green, and the buds brown. The flower buds open in February or March before the leaf buds, and each produces a silvery-grey inflorescence or catkin, spoken of familiarly as a "pussy" catkin. Some catkins remain green and contain pistillate flowers; others, on different trees, become yellow owing to the abundance of pollen produced by their staminate flowers.

(*h*) Hazel twigs have purplish-brown bark, while the buds are green, marked with brown lines, and are arranged alternately on the stem. Like the willow, the tree produces its flowers very early in the year, before the foliage leaf buds open. The staminate catkins, known as "lambs' tails", are long and slender, and sometimes may be found on the trees at Christmas-time. They produce an abundance of pollen, which is scattered as the catkins sway in the breeze. On the same tree may be found the pistillate catkins, resembling foliage buds in appearance, but distinguished by the tuft of crimson stigmas protruding from their tips.

PRACTICAL WORK

1. Study the colour of the flowers in a definite area, such as a moor or a wood. Note the chief colours in each season, and the way they blend together.

2. Make a list of the plants found growing in hedgerows, and compare with a list of those growing in fields. Note specially any which you find in both places.

3. Keep an account of the plants you find growing in a beech wood, and also of those found in a mixed wood. Account for any striking differences between the two lists.

4. Collect and draw plants found growing in very dry places, and also in very damp places. Notice whether the first group of plants have any characteristics in common, and whether the second group have. Try to suggest why there should be such a difference between the two types of plant.

5. Examine the plants in a hedgerow or field in a valley and keep a note of the time of flowering. Look for the same species of plants growing high up on a hill-side, and compare the time of flowering with that of the valley plants. Account for any differences you may find.

6. Make a plan of a selected part of a hedgerow, field, common, wood, marsh, or seashore. Show on the plan, by means of different methods of shading, any differences in soil in the area you select.

7. Examine the plants growing in the selected area. Mark on the map any large patches of one kind of plant, such as ground-ivy in the hedgerow, coltsfoot in a field, gorse on a common, beech-trees in a wood, kingcups in a marsh, and glasswort on the seashore.

8. Keep a record of the plants found each month in your special area. Note the height of the plant and the rate of growth, the time of flowering and fruiting. Is the plant annual, biennial, or perennial?

9. In this way study the area during successive years and compare your records for the same month in each year.

10. Make a list of all the trees which flower before the foliage leaves open. You should begin this work in January.

11. Examine a hen's egg. Note the shell, the two shell-membranes—separated at the broad end by a space, containing air—the white or albumen, and the yolk. The yolk is kept in position by two twisted tough cords attaching it to the inner membrane, one at the broad and the other at the narrow end. The red spot on the yolk is the part from which the chick will develop.

12. Make up an experiment to show that the eggshell is porous, and will allow the passage of both air and water.

13. Collect and draw as many different types of true fruits as you can.

14. Make a collection of false fruits and, when possible, of the flowers from which they were produced. In each case draw a half-flower and a section of the fruit, as well as the entire fruit.

15. Make clearly labelled drawings of fruits scattered by wind, by animals, and by water. Always make enlarged drawings of small fruits.

16. Press the leaves you have collected and mount them as you did your wild flowers, labelling each one clearly.

17. Keep an account of all the birds that migrate to warmer countries in autumn.

18. Keep an account of the birds coming from colder countries to Britain in autumn.

19. Collect from the trees in winter as many twigs as you can. Draw them, and label your drawings clearly.

20. Keep the twigs in water, or in culture solutions such as you used for experiments described in Chapter XIII. Make drawings of them, showing buds at different stages of development.

21. Make sketches showing the winter form of the trees whose buds have been described in this chapter. Notice the form of the same trees in summer.

22. Try to force the opening of buds by placing twigs, such as those of lilac, for ten hours in water kept at a temperature of 86° F. You can use a water-bath to do this. Afterwards the twigs may be kept in a warm place in water in the usual way, or in a water-culture solution.

23. Take a young runner bean seedling growing attached to a support in a pot, and fix a sheet of glass horizontally about six inches above the apex of the plant. Fix a pointer in a horizontal position between the tip of the plant and the glass, so that the tip of the pointer is in a vertical line with the tip of the plant. Look vertically down on the plant, and mark on the glass with a spot of ink the position of the pointer as it appears when its tip is in line with your eye and the apex of the plant. Repeat these dots at hourly intervals. Account for your results.

24. Repeat experiment 23, using a young growing plant of hop.

25. Cut two circles of strong brown paper, making them larger than the area of the top of each pot used in the two previous experiments. Cut along a radius of each paper circle, so that it fits around the base of the plant and covers the soil in each pot. Tie the paper down firmly to prevent the soil from falling out, and fix each pot in an inverted position. At the end of a week examine the plants and try to account for the results obtained.

EXERCISES AND QUESTIONS

1. Make a list of the different kinds of places in which birds build nests, describing the type of nest made in each case.

2. Find out whether the one kind of bird always lays the same number of eggs in one brood.

3. Name any birds which do not build a nest. Say in each case where the eggs are laid and what they are like.

4. Compare the beaks of insect-eating birds with those that feed on fruits and seeds.

5. Describe the different kinds of feet found among birds, and say how, in each case, the type of foot is connected with the habits of the bird.

6. Which birds are most active at night? Give reasons for this.

7. By what means does a bird make up for the lack of teeth?

8. Describe the flight of a bird.

9. Account for the high temperature of a bird's body.

10. Why does a bird usually fly with the wind and not against it?

11. Try to find out where the cuckoo lays her eggs, and give an account of the habits of this bird.

12. Describe the habits of young birds born naked, and of those covered with down or covered with feathers.

13. What is meant by a dry, dehiscent fruit? Write an account of the different types you know.

14. What is a false fruit? Why are apples, figs, rose-hips and strawberries described as false fruits?

15. "The horse-chestnut is a seed, but the sweet chestnut is a fruit." Is this statement true? Give your reasons.

16. Has the dying down of the stem of a plant any advantages over the falling of leaves as a means of protection during the cold months of the year? Give reasons.

17. Name any trees in which flowers are produced in different buds from those producing foliage leaves,

18. Mention the ways in which willow and hazel catkins are adapted for wind pollination.

19. By what means may flowers attract insects for the purposes of pollination? Give examples in each case.

20. Compare the secretion of silk by a spider and by any insect.

21. Why are the spokes of a spider's web not sticky?

22. Find out all you can about spiders that do not spin webs. How do these spiders catch their prey?

23. Why do some plants climb?

24. Describe any plants which climb by means of prickles, and say from what part of the plant the prickles are formed.

25. From which parts of a plant may tendrils be formed? Give examples in each case.

26. Name any plants using their stems for climbing. In each case describe the method of climbing.

27. By what means does a tendril twine round a support? Account for the fact that in most tendrils a double spiral is formed.

CHAPTER XVII

HOW FLOWERING PLANTS ARE CLASSIFIED

IF you have done the practical work at the end of Chapter V, you should have discovered that certain flowers closely resemble one another in structure, while others have marked differences. Plants bearing flowers with certain resemblances are grouped together into a Natural Order. There are nearly five hundred of these Orders, and only a very few, containing some of the flowers commonly found in Britain, are described here.

The grouping of the plants is determined mainly by the structure and arrangement of the pistil and stamens, but, like the café-au-lait,[1] many flowers possess some of the characters of more than one family. In such cases the plant is included in the Order containing the members it most closely resembles.

The diagrams showing half-flowers have been drawn to show the parts seen when the flower is cut longitudinally through the middle into two exactly similar parts. The floral diagram represents a section taken transversely through the flower, and shows only the upper surfaces of the cut parts. If you cut transversely through a bluebell, you might get a section showing perianth leaves and ovary, or one showing perianth leaves and anthers, but ovary and anthers could not both be seen in one section, since they are arranged at different levels in the flower. In the floral diagram, however, both are drawn. It is assumed that all parts of the flower would be cut through together, and that they would be arranged on the

[1] Chapter II, p. 17.

circumferences of circles. As many details as possible are shown in the floral diagram, the axis of the stem bearing the flowers being represented by a dot or cross, nectaries by tiny semicircles sometimes attached to perianth leaves, and joined parts by lines connecting the separate segments. Since, when bracts are present, the flowers arise in their axils, the position of the bract is shown on the opposite side to that of the axis.

When describing the parts of a flower, certain abbreviations may be used. **P** stands for **perianth, K** for **calyx of sepals, C** for **corolla of petals, A** for **andrœcium of stamens,** and **G** for **gynæceum or pistil of carpels.** Brackets placed round a number indicate that the segments represented by it are joined together, while a horizontal line drawn below a number signifies that the part of the flower represented by it is superior. To show inferior parts, the line is drawn above the number.

The chief characteristics of each of the two great divisions of flowering plants, Monocotyledons and Dicotyledons, have already been discussed in Chapter V.

LEGUMINOSÆ—THE PEA FAMILY.

The plants of this family usually have compound pinnate leaves. Often some of the leaflets are modified to form tendrils. The roots of many members bear tubercles inhabited by nitrifying bacteria. The inflorescence is racemose, and in all the British plants belonging to the family the flowers are irregular, the stamens are perigynous, and the fruit is a pod. The flower is somewhat butterfly-shaped, and hence this group of the family is known as the PAPILIONACEÆ. To it belongs the **sweet pea.**

The shape of the flower is connected with the method of pollination, which is usually effected by bees. When the stigmas of one flower receive pollen from the stamens of another, the process is described as cross-pollination. An insect alighting on the wings of the **broom** pushes the small keel down, and as the stamens and pistil are compressed within it, they spring out with a jerk. The five shorter stamens emerge first, and, striking the under surface of the bee, deposit their pollen. Immediately afterwards the five long stamens and the stigma are shot out, and the latter, striking the back of the insect, receives pollen, while that from the long stamens is scattered in a shower over the insect's back. In this case, therefore, in cross-pollination, pollen is received from the back of the insect, while in the sweet pea it is received from the ventral surface. Since the keel is so small, the stamens and pistil cannot fit back into it after pollination, but remain protruding from the flower, and so, should pollination not

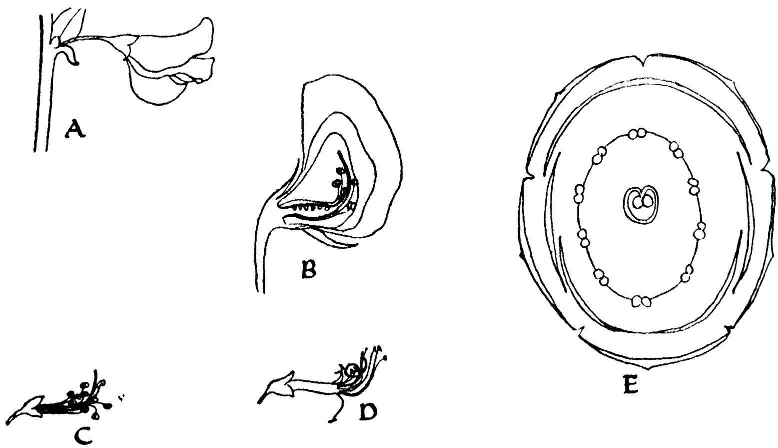


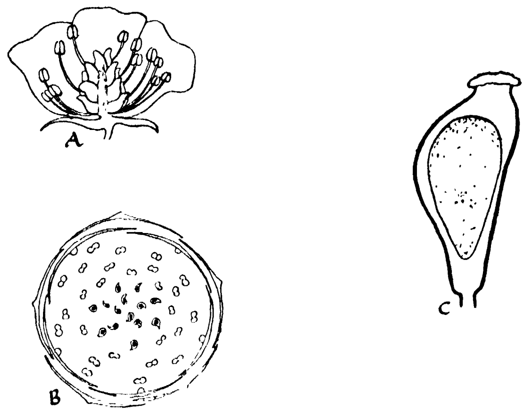
FIG. 103.—BROOM.

F lower. $\times \frac{1}{2}$. B. Half flower. $\times$ 1. C. Essential organs before pollination. $\times \frac{1}{2}$
D. Essential organs after pollination. $\times$ 1. E. Floral diagram.

take place during the first visit of an insect, the ovules never become fertilised, whereas the sweet pea may receive repeated visits from insects as the parts of the flower return to their original position after each visit. Other plants belonging to this family are **laburnum, bird's-foot trefoil, gorse, medick, runner bean, clover,** and **broad bean.** The pod of the medick is black when ripe, and becomes spirally twisted. It may be indehiscent, in which case it is furnished with hooks, so that it is dispersed by animals. The leaves and many of the branches of gorse are modified to form spines.

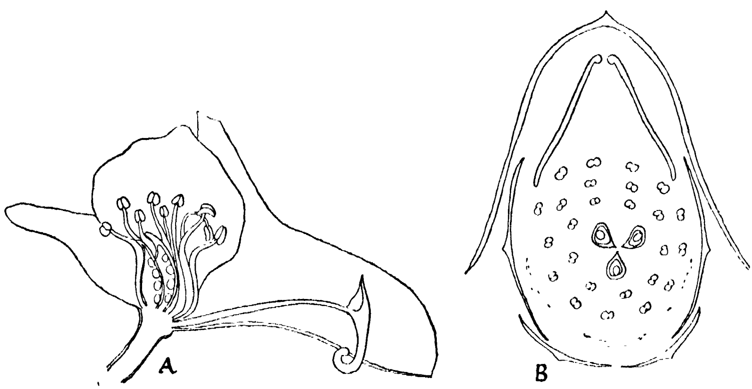
RANUNCULACEÆ—THE BUTTERCUP FAMILY.

Most of the plants belonging to this family are herbs. The leaves are simple, often much divided, and usually alternate.



BUTTERCUP.

A. Half flower. × 1. B. Floral diagram. C. Section of achene. × 20.



MONKSHOOD.

A. Half flower. × 2. B. Floral diagram.

FIG. 104.

Many of the plants have a root-stock. The inflorescence is generally a raceme or a cyme. The flowers may be regular or irregular, and the fruits are compound, being collections of achenes or follicles.

Buttercup ($K_5C_5A_\infty \underline{G_\infty}$). The flower is regular, and hypogynous with brightly coloured petals, and at the base of each is a nectary. Pollination is effected by insects, which are attracted by the colour and the nectar. Since the flower is not tubular, its parts being flattened and spread out, it is visited by short-tongued insects, and the pollen is brushed off on the ventral surface of their body. The fruit is a collection of achenes.

Monkshood (*Aconitum*) has an irregular flower, with brightly coloured sepals forming a hood, and two of the petals are modified to form nectaries on long stalks inside the hood. The stamens shed their pollen before the ovules are ripe, and when the bumble-bee alights on the lower petals and pushes its long tongue up into the hood to get the nectar, the pollen is brushed off on to the bee's ventral surface. The stamens then curl back, and when the flower is visited again pollen is brushed off on to the stigmas.

Larkspur (*Delphinium*) also has an irregular flower with a single spur in which are two nectaries. The fruits of both larkspur and monkshood are collections of follicles. The **marsh marigold** or **kingcup** has nectaries on the carpels, and the yellow floral leaves are sepals. In **hellebore, anemone, globe-flower**, and **clematis** the sepals are also conspicuous. Clematis is a shrub, climbing by means of petioles. The leaves are compound and opposite. The flowers are green, and the achenes have feathery styles and are dispersed by wind.

The fruit of **love-in-a-mist** (*Nigella*) is a capsule, and that of **baneberry** is a berry. Other common plants belonging to this family are **water-crowfoot, meadow-rue, mousetail, columbine, peony,** and **lesser celandine.**

SCROPHULARIACEÆ—THE SNAPDRAGON FAMILY.

All the British members of this family are herbs, with alternate or opposite leaves with no stipules. The inflorescence is usually either a cyme or a raceme. The flowers are irregular and the petals joined. The pistil is formed of two carpels, the ovary is superior, the ovules have axile placentation, and the fruit is a capsule. There are three chief types of flower, differing from each other in the number of sepals, petals, and stamens.

Snapdragon has the commonest form of flower ($K_{(5)}$ $C_{(5)}$

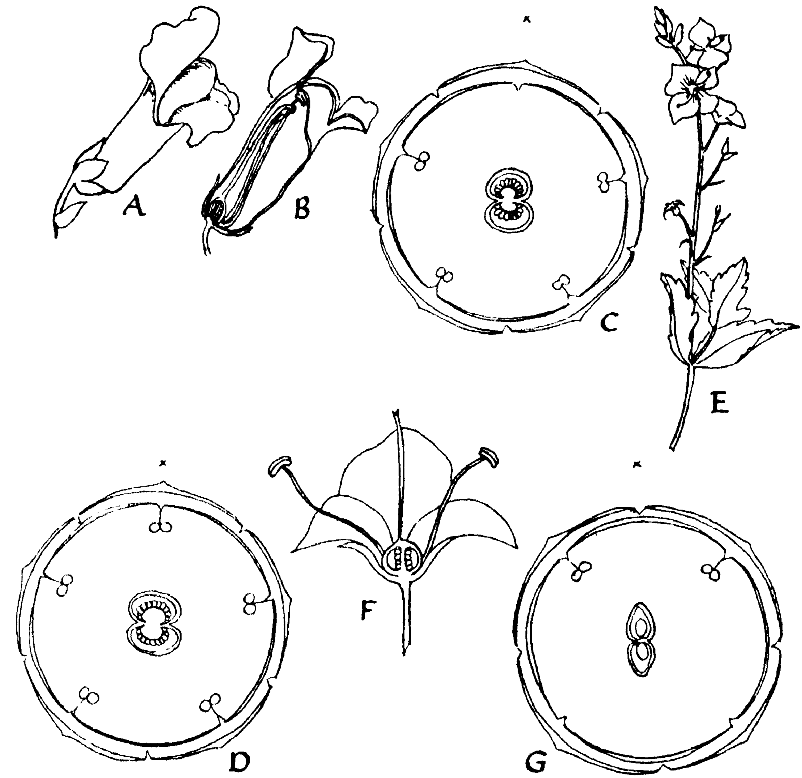


FIG. 105.

A. Flower } × 3/5. } of snapdragon.
B. Half flower }
C. Floral diagram }
D. Floral diagram of mullein.

E. Inflorescence × 3/5. } of speedwell. (*Veronica.*)
F. Half flower × 4. }
G. Floral diagram }
× Indicates axis of stem.

A_4 $G_{(\underline{2})}$). The corolla tube is wide and long, and the orange-coloured nectaries are at the base of the pistil, so only long-tongued insects can reach the nectar. You have no doubt often pinched a snapdragon flower to make it open and show the stamens and stigma beneath the upper lip. The only insect that can force down the lower lip is a strong one, the bumble-bee. As the bee inserts its long tongue to get the nectar, the stigma brushes against the back of the insect before the anthers do. The fruit of a snapdragon is a capsule opening by two pores.

The second type of flower is the **mullein** ($K_{(5)}C_{(5)}A_5G_{(\underline{2})}$). The flower is regular, and the stamens have very hairy filaments. There is no corolla tube, so the flower is pollinated by short-tongued insects.

The third type of flower is seen in **speedwell** (*Veronica*) ($K_{(4)}C_{(4)}A_2G_{(\underline{2})}$). The flower is irregular, as the petals are slightly unequal. Hover-flies, in their attempt to get at the nectar, effect pollination by brushing against the stigma first, receiving pollen on their backs as they fly upward.

The flower of the **figwort** is similar to that of the snapdragon, but the stigma is ready for pollination before the pollen in the stamens is ripe. The flower is one of the few that are visited by wasps. If you look at an inflorescence you will see that the youngest flowers are at the top, and in these the stigmas are ready to *receive* pollen, while in the flowers at the base the anthers are ready to *shed* pollen. Wasps, when visiting flowers, always start with the flowers at the top of the stem and work downwards, while bees work in the opposite direction. A wasp alighting on the lower lip of a young flower of figwort brushes against the stigma, and the pollen from the insect's ventral surface is brushed off. In this way the young flowers become pollinated, and when the wasp reaches the older flowers at the bottom of the inflorescence it receives a fresh collection of pollen on its ventral surface.

Other flowers belonging to this family are the **foxglove, musk, toadflax**, and **toothwort.** The family also includes **eyebright, cow-wheat, red rattle, yellow rattle**, and **bartsia,** all of which are semi-parasites, since they obtain part of their nourishment by attaching their own roots to the roots of other plants.

PRIMULACEÆ—THE PRIMROSE FAMILY.

Plants belonging to this family are herbs with simple, undivided leaves. The inflorescence may be an umbel or a raceme; sometimes the flowers are solitary. They are regular, the parts are arranged in fives, and the united petals form a tube. The stamens are *opposite* the petals, and joined to them. The pistil is superior and the placentation free-central. Nectar may be found at the base of the ovary. The fruit is a capsule, opening usually by teeth, but in the scarlet pimpernel by a lid.

The primrose ($K_{(5)}C_{(5)}A_5G_{(\underline{5})}$). If you examine primroses, you will find that some flowers have a long style, and the stamens situated half-way down the pollen tube, while others have a short style, and the stamens above it at the top of the tube. The primrose is therefore said to be dimorphic (Gk. *di*, two; *morphos*, form); the **cowslip, oxlip,** and **primula** are also dimorphic. In the long-styled or pin-eyed form, self-pollination is prevented by the position of the anthers. The flower is visited by long-tongued insects, and the pollen collects about half-way along the proboscis when the insect pushes it to the bottom of the corolla tube for nectar. When the insect flies to the thrum-eyed type of flower, the pollen is in the right position on the proboscis to be brushed off by the stigma half-way down the tube. The pollen from this flower adheres to the base of the insect's proboscis, and

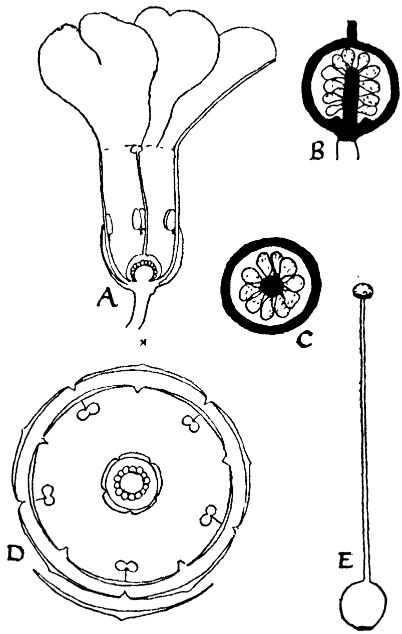


FIG. 106.—PRIMROSE.

A. Half flower. × 1.
B. Longitudinal section of ovary. } × 5.
C. Transverse section of ovary. } × 5.
D. Floral diagram.
E. Pistil from long-styled flower. × 2½.

from this position it is easily transferred to the stigma in the long-styled flower. The dimorphic flowers thus ensure cross-pollination. Other plants belonging to this family are the cowslip, oxlip, primula, cyclamen, scarlet pimpernel, yellow pimpernel, creeping-jenny, and loose-strife.

COMPOSITÆ—THE DAISY FAMILY.

Plants belonging to this family are nearly all herbs. The leaves are usually alternate and may be hairy. The inflorescence is a capitulum, surrounded by a whorl of bracts, looking like a calyx, but really the bracts belong to the whole inflorescence, supporting and protecting it during its development. The flowers are small, and are called florets. The calyx is often hairy, forming a pappus (Gk. *pappos*, down). The petals are joined to form a tube or strap-shaped structure. The stamens have their filaments joined to the petals and their anthers united in a ring. The ovary is inferior, so that the flower is epigynous. The fruit is an achene.

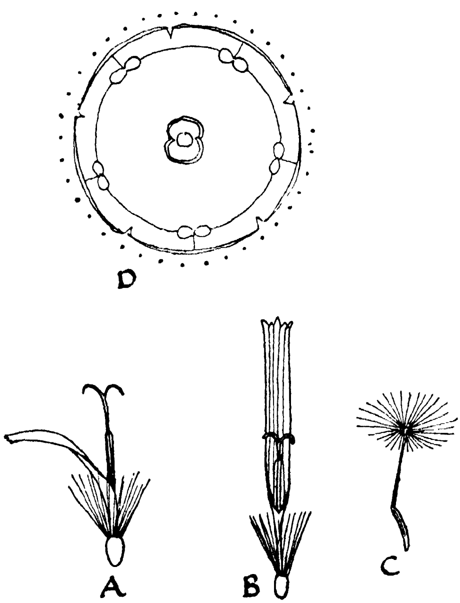


FIG. 107.—DANDELION. × 1½.

A. Floret side view. B. Floret front view.
C. Fruit. D. Floral diagram.

The dandelion ($KC_{(5)}A_{(5)}G_{(\bar{2})}$). Each floret of the dandelion is strap-shaped. The calyx is in the form of a pappus of hairs, which remains attached to the ripe fruit, aiding its dispersal by wind. The yellow petals form a tube at the base. The two stigmas are folded together at the end of the short hairy style.

The anthers open and shed their pollen towards the centre of the flower, and as they mature before the pistil, the pollen collects in the anther tube. Through this the style and folded stigmas grow, carrying up pollen on their hairy outer surfaces. The stigmas then open, curling away from each other, so that when the flower is visited by insects cross-pollination may take place. Should this not happen, the stigmas may curl right back until their upper surface comes into contact with the pollen on the style, and so they are self-pollinated. Since the nectar is produced at the bottom of the long corolla tube, the flowers are visited by long-tongued insects.

In many inflorescences there are two kinds of florets, the

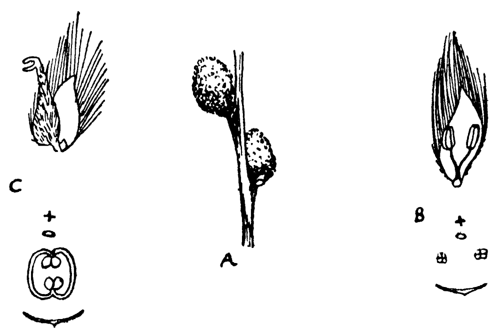


FIG. 108.—WILLOW.

A. Staminate inflorescences. B. Male flower (much magnified) and floral diagram C. Female flower (much magnified) and floral diagram.

strap-shaped or ray florets on the outside of the inflorescence surrounding smaller disc florets in the middle. The ray florets of the **daisy** have a pistil but no stamens; the outer florets of the **cornflower** have neither pistil nor stamens, and are brightly coloured, serving merely to attract insects.

The massing together of the florets into a capitulum renders the inflorescence conspicuous to insects, and many flowers may be pollinated by one insect. Many members of this family are common weeds, and include the **hawkweed, chicory, marigold, coltsfoot, groundsel, thistle, and chamomile.**

Other plants are the **Michaelmas daisy, sunflower, golden rod, Dahlia,** and **Jerusalem artichoke.**

SALICACEÆ—THE WILLOW FAMILY.

Plants included in this family are nearly all trees and shrubs, often reproducing vegetatively by suckers. The flowers are grouped in special inflorescences described as catkins, and each falls off as a whole when the flowers are dead. Each flower has no perianth, and consists only of a large conspicuous bract and either stamens or pistil. There is usually a small nectary, but pollination is often carried out by the wind, since the flowers open before the leaves unfold. The fruit is a capsule.

The willow. The male, or staminate, and female, or pistillate, catkins are borne on different trees. Each catkin is made up of an axis bearing numerous tiny flowers, each with a hairy, silvery green bract, giving the catkin its silvery appearance. The male catkin appears yellow when mature, owing to the large anthers, while the female one becomes greener in colour. In each male flower there are two or more stamens and a nectary at the base. There is also a nectary at the base of the female flower, the ovary is long, the style short, and there are two stigmas. The flowers may be pollinated by insects.

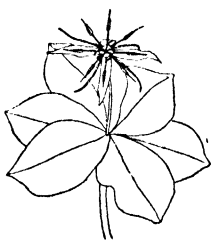


FIG. 109.
HERB PARIS. × ½.
An unusual specimen with six leaves.

Other plants belonging to this order are the **poplar** and **aspen.**

LILIACEÆ—THE LILY FAMILY.

Plants belonging to this family are mostly perennial herbs, with bulbs or rhizomes. The inflorescence is often a raceme, and the flowers are regular, with a superior ovary. The fruit is a capsule or berry.

A common type, the **bluebell**, has been described in Chapter V.

Herb Paris is peculiar in that the leaves are net-veined, and the parts of the flower are $P_{4+4}A_{4+4}G_{(\underline{4})}$.

In the **butcher's broom** the flowers are small and are borne on what are apparently leaves, but are really modified branches. The flowers contain either stamens or pistils, that is, they are *unisexual.*

Among the plants belonging to this order are **Solomon's seal, tulip, onion, asparagus, lily of the valley, star of Bethlehem, grape** hyacinth, and **bog asphodel.**

GRAMINEÆ—THE GRASS FAMILY.

This family is a large one, its members being of world-wide

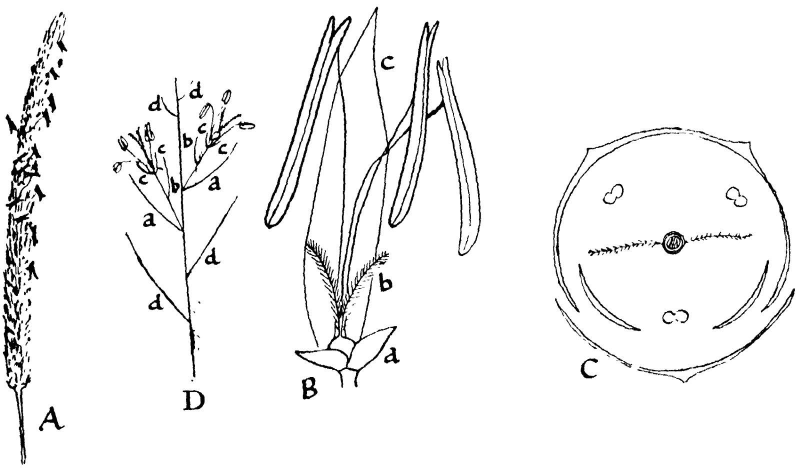


FIG. 110.—CAT'S TAIL GRASS.

A. Compound spike. $\times \frac{2}{3}$.
D. Diagram of spikelet.
a, Flowering glume; *b*, palea; *c*, lodicules; *d*, empty glume.
C. Floral diagram.
B. One flower (much enlarged).
a, Lodicules; *b*, feathery styles; *c*, palea.

occurrence, and to it belong many plants of great importance to man. Most of the plants are herbs; their leaves have very long bases growing up round the stem, and each leaf base forms a split sheath. The stem is usually hollow, and bears prominent nodes, from each of which several branches or leaves may arise, giving the plant its tufted appearance. Just above each node is a special group of cells, and the growth of these enables the plant to erect itself when it has become horizontal. You have probably noticed that when grass is trodden down it does not remain flat for long, whereas primroses or other herbs do not recover after being crushed. The inflorescence of a grass is either a compound raceme, as in oats, or a compound spike, as in wheat. Each simple inflorescence is known as a **spikelet.** Each spikelet is a group of flowers in which no true perianth is developed. Usually at the base of the spikelet are two bracts or glumes with no flowers in their axils. One flower is produced in the axil of each of the following glumes, the flowering glumes, while the uppermost glumes again are empty. The tips of the flowering glumes may grow out to form long bristles or awns. On each flower stalk, as you may see in Fig. 110, is found a special bract, the palea, and between this and the flowering glume the flower is entirely hidden when young. Above the palea, on the flower stalk, are two very small outgrowths, the lodicules, which may represent the perianth; each flower produces three stamens, and a pistil formed from one carpel. The superior ovary contains one seed; the stigma is two-lobed and feathery. The fruit is an achene, in which the seed coat and ovary wall become fused, and the seed has endosperm.

The most conspicuous parts of a grass flower are the anthers. These are large, and are attached in such a way that they appear to see-saw on the long filament. This method of attachment is described as versatile. Each anther contains a large quantity of dry powdery pollen. Since the flowers are green and inconspicuous, and produce no nectar, they do not attract insects, but the pollen is distributed by the wind, and is readily caught by the two feathery stigmas.

Belonging to this order are the cereal plants, **wheat, oats, rye, barley, rice,** and **maize,** and also the **sugar cane** and **bamboo**

POLLINATION.

Amongst the plants that have been described in this chapter, you will see that cross-pollination takes place much more frequently than self-pollination. A few flowers, such as grasses which produce large quantities of pollen, and have conspicuous anthers, and poplar, where the stamens are very numerous, have their pollen scattered by the wind. Plants which rely upon the visits of insects to effect pollination may employ various devices to attract them. Thus, like the lily, they may produce scent; like the cornflower and marsh marigold, they may have a brightly coloured perianth; like the willow, they may have nectaries, or they may have more than one of these means of attraction. Cross-pollination is ensured in some plants by the ripening of the stamens before the pistil, as in the dandelion, or of the pistil before the stamens, as in the figwort. The dimorphic flowers of the primrose attain the same purpose. Some flowers are visited by flies, some by bees, and the figwort by wasps. According to the position of the nectary, the pollen may get brushed off on to the ventral surface of the insect, as in the sweet pea, or to the dorsal surface, as in the broom. Since so many devices are employed by plants to ensure cross-pollination, it must have some advantage over self-pollination. From the many experiments performed by Darwin and other botanists on pollination, it seems probable that more vigorous plants producing a larger number of seeds are obtained when stigmas are not pollinated by pollen from the same plant.

PRACTICAL WORK

1. Examine each of the flowers mentioned in this chapter. Write the floral formula for each, and make drawings of half-flowers, longitudinal sections, and floral diagrams.

2. In your collection of wild flowers try to find those showing the characteristics of any of the families described in this chapter, and say to what family each belongs. Give reasons for your classification.

3. Select a sweet pea plant growing in your garden, and before the flowers open protect it from the visits of insects by covering it with fine muslin. Use fine scissors and forceps to remove from some of the flowers the stamens before they are ripe. Tie a labelled paper bag around each flower so treated. Watch the flowers to see if they produce seed.

Transfer some ripe pollen to the stigmas of other flowers similarly treated, and cover them with paper bags. Watch these flowers to see if they produce seed. Try to germinate any seeds produced in either case.

QUESTIONS

1. Describe the methods adopted by flowers to ensure cross-pollination.

2. Distinguish between the characteristics of wind-pollinated and insect-pollinated flowers.

3. Mention the advantages connected with cross-pollination.

4. Describe the pollination of any flower to which the pollen is carried on the ventral surface of an insect.

5. Describe the pollination of any flower to which the pollen is carried on the back of the insect.

6. Name any flowers in which the stamens are ripe before the pistil. Describe the method of pollination in each case.

7. Name any flowers in which the pistil is ripe before the stamens. Describe the method of pollination in each case.

8. What differences in shape would you expect to find between flowers pollinated by short-tongued insects and those pollinated by long-tongued insects?

9. What is meant by (*a*) pollination, (*b*) fertilisation? Why is it incorrect to say that flowers are cross-fertilised by insects?

10. The mullein and the primrose both have five sepals, five petals, and five stamens. Why are these flowers included in different Natural Orders?

EXAMINATION QUESTIONS

UNIVERSITY OF LONDON GENERAL SCHOOL EXAMINATION

BIOLOGY

1. Describe and compare the structure of *Amœba* and *Spirogyra*. How do these organisms differ in their source of nutriment?

2. Describe the respiratory system of a typical mammal and explain the importance of respiration in animals and plants.

3. Give an account of the structure and mode of life of *Hydra* and *Spirogyra*. Why is *Hydra* regarded as an animal and *Spirogyra* as a plant?

4. Describe the stomach and liver of a typical mammal and state as fully as you can the functions of each.

5. Describe the alimentary canal and its associated glands in a mammal. State briefly the functions of the various parts.

6. Describe briefly the vascular system of a mammal (excluding the structure of the heart), and compare its functions with those of the "vascular system" (conducting strands) of a flowering plant.

7. Describe the life history of a fern. Sketch a prothallus, indicating all the parts that can be made out with the aid of a hand-lens. How could you obtain a crop of fern prothalli?

8. Explain carefully the essential differences in nutrition between the Algæ and the Fungi, and briefly describe one example of each of these classes.

9. With the aid of labelled diagrams, compare the organs of locomotion in a fish, frog, a bird, and a mammal, and indicate how far they are constructed on a common plan.

10. By what characters could you distinguish between a fish and an amphibian? Why is an amphibian regarded as a higher type than a fish?

11. Compare the external features of a tadpole and an adult frog. How far do you consider the differences you mention to be related to the difference in their mode of life?

12. Write a fully illustrated account of the metamorphosis in the life history of a butterfly and describe the external features of the adult insect.

13. Write an account of the external features and mode of life of an earthworm and describe the part played by earthworms in the formation of the soil.

14. What conditions are necessary for the germination of seeds? How could you prove the truth of your statements by experiment?

15. What do you understand by photo-synthesis (carbon assimilation) in plants? Why is this process of great importance in Nature? How would you test for the products of photo-synthesis in a green leaf?

16. Give an account of the structure of *Amœba* and yeast and state the principal differences in their modes of nutrition.

17. How do stems and roots respond to the stimulus of (*a*) light, (*b*) gravity? Describe experiments that you have performed in proof of your statements.

18. State precisely what you understand by *respiration*. What is the use of this process to an organism? How could you prove by experiment that respiration takes place in (i) an animal, (ii) a green plant?

19. How would you investigate the changes that take place in the air inside stoppered glass jars containing (i) a live mouse, (ii) a potted green plant, when both jars are exposed to light? Briefly explain these changes.

20. Describe the flowers of the willow and poplar and show how the differences are related to their methods of pollination.

21. Describe any four fruits which are dispersed by animals and state clearly how the dispersal takes place.

UNIVERSITY OF OXFORD SCHOOL CERTIFICATE EXAMINATIONS

GENERAL AND AGRICULTURAL SCIENCE

1. Compare the ways in which most plants and most animals get their food. Show how the structure of plants and animals is adapted to enable them to obtain their food, and mention as many plants and animals as you can which do not obtain their food in the usual way.

2. On what grounds do we decide whether a given organism should be regarded as an animal or a plant? Point out any difficulties which

arise in attempting to make a rigid distinction between animals and plants.

3. What is the value of a scientific classification of, for example, animals? Upon what principles is such a classification based?

State, giving reasons, whether you would place a snake and an eel in the same class.

4. What do you understand by an insect? Give an account of the life history of any one insect you please.

5. For what reasons do we regard spiders and flies as belonging to different natural classes?

Write a short account of the life history and habits of any one insect (e.g. the common house-fly).

6. On what grounds do we classify fishes as animals? Give a short account of the life history and habits of any one fish.

7. On what grounds do we place frogs and snakes in different classes of animals?

Give an account of the life history of either (*a*) the common frog, or (*b*) one variety of snake.

8. What are the main differences between vertebrate and invertebrate animals?

Describe briefly the structure of some one animal belonging to each class. (Do not select an insect.)

9. Draw diagrams of three stages in the germination of any (*a*) dicotyledonous, (*b*) monocotyledonous seed that you have studied. Name the diagrams fully and state briefly the main differences in (*a*) the structure, (*b*) the mode of germination of the seeds.

10. Describe a grain of wheat and explain what happens during the germination of the seed. (Agric. Sc.)

11. Give an account of the life history and habits of one of the following: (*a*) the common frog, (*b*) the dragon-fly, (*c*) the honey bee. Assign the animal you choose to its proper class, giving reasons.

12. Give an account of the life history of some insect that you have studied which undergoes metamorphosis. State clearly the special advantage which each stage in its life history affords to the insect you choose.

13. Why do plants store up food? In what part of a plant may food be stored? Illustrate your answer as fully as possible from vegetables which we eat.

14. Why do plants store up food? In what parts of the plant is food deposited? Give examples.

15. What is meant by respiration? What is its importance to plants? Describe *two* simple experiments which show that respiration takes place in plants.

16. What substance makes the leaves of plants green? Of what use is this substance to the plant? Describe some simple experiments to illustrate your answer.

17. Give a short account of the structure of the leaf of the bean plant and explain how the leaf behaves towards carbon dioxide in the air. (Agric. Sc.)

18. What elements are usually present in plants? Describe shortly the source. (Agric. Sc.)

19. What elements are usually present in plants? Describe shortly the source of each, and state whether each is necessary for plant nutrition.

20. From what sources does a plant obtain its food? Describe two experiments which show that a plant does obtain food from one of the sources you mention.

21. What are the chief ways in which the stems of plants are modified to enable them to perform special functions? Give as many examples and drawings as possible.

22. What is meant by the term "weathering"? How does this process result in the formation of soil? (Agric. Sc.)

SCHOOL CERTIFICATE QUESTIONS SET BY THE OXFORD AND CAMBRIDGE SCHOOLS EXAMINATION BOARD

GENERAL SCIENCE

1. Make a sketch of a dissection **either** of a frog **or** of a rabbit, to show the parts of the alimentary canal and the adjacent structures.

2. Describe briefly the life history of a fly. In what way are flies a danger to health?

3. What is meant by a parasite? Describe a plant and an animal parasite.

4. By what agencies is soil formed from rocks?

5. What are the reasons for mixing lime with the soil used for cultivation?

6. Explain the part that carbon dioxide plays in the life of a green plant.

SCHOOL CERTIFICATE AND MATRICULATION QUESTIONS SET BY THE JOINT MATRICULATION BOARD OF THE NORTHERN UNIVERSITIES

NATURAL HISTORY

1. Identify and make properly labelled drawings of two of the specimens A, B, C, D.

A. Half a bean seedling in spirit.

B. Pupa of butterfly, or antennule of crayfish.

C. Pelvic girdle of frog.

D. Large specimen of *Culex* larva.

2. Identify and make properly labelled drawings of two of the specimens A, B, C, D.

A. Flower of sweet pea.

B. Swimmeret of crayfish and micro-slide of head of butterfly, showing coiled proboscis, etc.

C. Lower jaw of cat or dog.

D. Pelvic girdle of frog.

3. How do the following animals obtain their food supplies: (*a*) Amœba, (*b*) Hydra, (*c*) Earthworm? Give the details of food capture and state where the food is digested.

4. Name the chief chemical elements which are found in animals and plants, and describe how plants obtain their carbon.

5. Describe the different functions which may be performed by the skeleton of an animal. (Give illustrations from the types you have studied.)

6. Describe experiments which may be made to illustrate the digestive action of the secretions of the stomach in a mammal.

7. What parts of a fish may be used as organs of locomotion (include also in your answer those organs which determine the direction of movement). Describe how the parts are used.

8. Describe the life history and habits of an aquatic insect which you have personally observed.

9. Mention two pond animals which must ascend to the surface to obtain air and two which can obtain their supplies from the air dissolved in the water. Describe how breathing takes place in each case.

10. How is the temperature of a so-called "warm-blooded" animal maintained? Mention and explain the action of any structures which

are related to the relatively high and constant body temperature found in the "warm-blooded" animals.

11. One of the characteristic features of all living creatures is sensitivity, the property of responding to stimuli. Illustrate this by reference to a plant and an animal.

12. Write a short essay on the importance of water to plant and animal life.

13. Describe simple experiments which may be made to find out how the direction of growth of a root is affected by gravity, by moisture, and by light.

14. What is meant by transpiration? What effect has (*a*) cold weather, (*b*) wind, on transpiration?

15. What is meant by asexual reproduction? Describe two examples from the animal types of your course and two from the plant kingdom.

16. Describe briefly where four of the following structures are to be found and state their function: (*a*) Stomata, (*b*) Lenticels, (*c*) Root-hairs, (*d*) Cotyledon, (*e*) Tendrils, (*f*) Stamens.

17. Make a sketch showing the appearance of beech or horse-chestnut twigs in winter. How would you determine the age of a twig by its external characters?

UNIVERSITY OF DURHAM SCHOOL CERTIFICATE EXAMINATION

BIOLOGY

1. What are the essential differences between the modes of nutrition of plants and animals?

2. What is meant by (*a*) "food of plants" and (*b*) "food of animals"? Explain the meaning of the word "food" in the two cases.

3. Describe any mammal with which you are acquainted and state some of its habits.

4. What is meant by "cross-pollination"? Describe in detail two common devices for securing it. Are all plants cross-pollinated?

5. Give a general description of the interrelationship of the plants and animals in any habitat with which you are familiar.

6. Give a detailed account of one case of the interdependence of plants and insects.

7. Mention examples of aquatic larvæ, and, choosing one, describe it and the animal into which it grows.

8. Describe the general external characters and sketch the life history of a fish.

9. Write an account of the life history of a wasp.

10. Describe the nest of a wasp and the general method of its formation.

11. What is a larva? What purpose does it serve? Describe one and its mode of life.

12. With examples, describe the methods of feeding to be observed amongst insects.

13. Describe the life history of the blue-bottle fly.

14. Why do bees visit flowers? State what happens during and after such a visit to any one flower which you have examined.

15. Sketch the life history of the daddy-long-legs, stating its importance in gardening and farming.

16. Give a general account of the life history of the currant moth and indicate circumstances which are favourable to it.

17. Give an account of plants which have underground shoots. Of what advantage to the plant is this mode of growth?

18. Set up an experiment, or experiments, to demonstrate *one* of the following:

(*a*) That both light and chlorophyll are essential for the formation of starch in leaves.

(*b*) That leaves give off water even after they are removed from a plant.

(*c*) That both water and oxygen are necessary for the germination of seeds.

19. In whatever position a seed falls to the ground the young seedling grows the right way up. By reference to experiments explain how this is brought about.

20. Explain briefly the relationship of plants and animals respectively towards (*a*) light and (*b*) gravity.

21. Define respiration and say how plants and animals are adapted to breathing in aquatic conditions.

22. Compare generally the methods of respiration in animals and plants.

23. What do you understand by respiration? State how the function is carried on in terrestrial and aquatic plants and animals.

24. Describe and compare a corm and a swollen taproot, explaining in each case the botanical structure and use of the structure.

25. Birds and some of the insects you have studied make nests. Describe one of each—a bird's and an insect's—stating its purpose.

26. Describe the principal ways in which plants climb. What advantage is secured by these methods of growth?

27. With examples, contrast plants and animals with reference to the storing of food.

28. Describe four different types of the dispersal of seeds by the wind. Why do plants disperse their seeds?

29. Describe the principal means, mentioning any examples with which you are familiar, by which plants are propagated, naturally or artificially, without seeds.

30. Describe the pollination of one wind-pollinated and one insect-pollinated flower. Point out the characteristic structural features of each type.

31. Point out the conditions necessary for the formation of starch in the plant, and state in which parts of the plant the starch is formed.

32. Give examples of animals which make stores of food and say for what purpose.

33. What is a fruit and how is it formed? Describe three kinds of fruit which are dispersed by animals.

34. Write a few notes on the habits of the frog and say how it is able to live above and below water.

INDEX

Bold figures indicate pages with diagrams.
Figures in italics indicate pages with definitions.

APPENDIX TO CHAPTER IX

The American Gooseberry Mildew (*Sphærotheca mors-uvæ*)

In all countries are found plants and animals living at the expense of others. Some of these may live only in one particular continent; others may be carried to different continents and thrive there, while others may have an almost world-wide distribution.

The American gooseberry mildew is an example of a parasite which was carried to Europe in 1900. It is very harmful to the gooseberry crops of both America and Europe, as it attacks the gooseberry bushes in both these continents. The mildew is a fungus and therefore incapable of building its own food from the simple materials used by green plants, so it secures its food from the sap of its host.[1]

In late spring and early summer you may see on the tips of the unfolding buds of certain gooseberry bushes a glistening web. Later this becomes powdery, owing to the formation of numerous thin-walled colourless spores. The web is really a mass of fine interlacing hyphæ which form erect branches, and from these the spores are separated. They are easily carried by the wind to other plants and to parts of the same plant, and, if they reach the leaves or young flower-buds, begin to grow, sending a little tubular outgrowth, the haustorium or sucker, into the cell of the host. Food passes from the cell into the sucker, so enabling the spore to continue its growth and send branches in all directions. At intervals the branches send haustoria into other cells to secure a good food supply.

[1] See p. 250.

All through the summer hundreds of these thin-walled spores are produced, but, if you watch the fungus during the early autumn, you will see the white patches begin to change colour. With the aid of a lens, you may then distinguish on the leaves and fruits of the host small white patches like spots of frost. These soon become first yellow, and then darker and darker brown until finally they are almost black. Each minute dark-brown, rounded object is a fruit body, or perithecium (Gk. *peri*, around; *thēkē*, case), and contains a case of eight spores which will rest until the following spring,

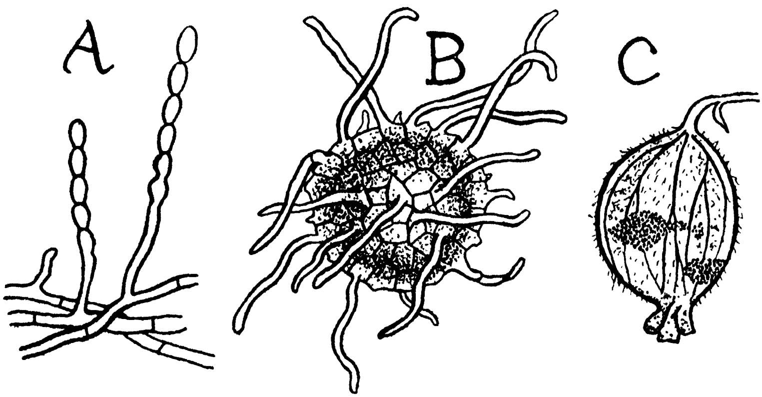


FIG. 111.

A. Conidia of a mildew.
B. Single perithecium of *Sphærotheca*.
C. Groups of perithecia on a Gooseberry.

protected by the thick wall of the fruit from cold and desiccation.

As soon as conditions are favourable the perithecium wall is burst, and then the spore case, liberating the spores. They may be distributed by wind or by insects crawling over the plants. Those spores which have reached gooseberry bushes will then germinate, sending suckers into the unfolding leaf and flower buds. When the hyphæ have grown sufficiently they produce the thin-walled summer spores. The production of these enables the mildew to be widely and quickly distributed, while the winter spores ensure its survival until its host can provide it with food again. The fungus is thus a very successful and dangerous parasite, and if steps were not taken to combat the disease by spraying the plants in the early stages of the attack and burning the badly diseased ones, fruit-growers would lose large numbers of their gooseberry bushes.

In Great Britain the fungus does not attack the fruit as much as it does the young shoots, which sooner or later, according to the violence of the attack, become shrivelled and curl. Thus even if the fruit be not directly attacked, it will be poorer in quantity and in quality because of the drain the fungus makes on the food supply. Fruits in the shade are more liable to attack than those in the sun.

The hop and rose mildews are very closely related to the gooseberry mildew and have similar life histories; another mildew often attacks the grape-vine. All these fungi are harmful parasites.

Ascaris, a Thread-worm

Amongst animal parasites, besides the tape-worm,[1] there are other "worms" for which many vertebrate animals may serve as host. *Ascaris* is a parasite belonging to a group of animals, the **Nematoda** (Gk. *Nematoda*, a thread), or thread-worms. Although these are worm-like in shape, their bodies are never segmented, and, although they produce in the body a fluid containing corpuscles and probably similar to blood, it never circulates in vessels but simply fills a space between digestive tube and muscle layer. The thread-worms therefore differ in many ways from the earthworm and other segmented worms.

Ascaris lumbricoides (L. *lumbricus*, worm) has a long reddish or greyish yellow body. The female may reach a length of forty centimetres, the male being somewhat shorter. The body is round in cross section, so that these parasites are often

[1] p. 194.

referred to as the "round-worms"; the diameter is about three millimetres. The ends of the body are pointed, the posterior end of the male being curved like a hook. There are no appendages of any kind to aid movement, so this may take place as a series of wriggles brought about by the contraction and expansion of muscle cells arranged in fibres running

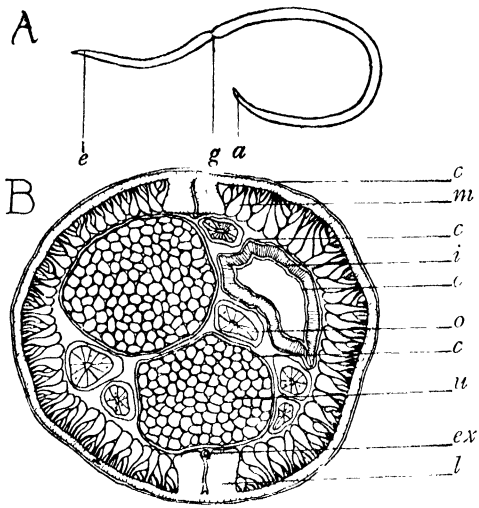


FIG. 112.

A. *Ascaris*—female. × 1.
B. Transverse section through middle region of *Ascaris* female.

a, anus; *c*, cuticle; *e*, opening of excretory system; *g*, opening of reproductive organs; *i*, intestine; *l*, lateral line; *m*, muscle cells; *o*, ovary; *u*, uterus; *ex*, excretory tube.

longitudinally. Since the parasite lives in the small intestine of its host, this smooth type of body is best suited for its mode of life.

The thread-worm lives surrounded by the dissolved foods of its host and absorbs these instead of feeding as most animals do. Possibly the simplest way of doing this would be to absorb the foods through its whole surface, but the thickness and nature of the skin prevents the parasite from doing this, so we find that it has a definite digestive tube, which, in the region of the mouth and of the anus, is lined with the same kind of thick cuticle as that covering the outside of the body. This cuticle is made largely of chitin, a substance which most animals can digest. Why, then, is the parasite not digested by its host? It is found that a worm will be digested if it die inside its host, but that the living worm secretes a substance, called an anti-body, which counteracts the effects of the digestive juices of the host. The cuticle is extremely thick and in it are a few glands. The thickness is probably of mechanical use to its owner, that is, it may enable the parasite to stand the stress and strain of its peculiar surroundings, in which a thin skin might easily be broken.

By means of the oxygen breathed in, the foods digested by an animal are used up in making new tissues and in producing heat and energy. Accompanying these processes, waste is excreted. In higher animals, the blood circulates the oxygen and food, and collects waste. *Ascaris* has neither breathing nor circulatory system, and lives in surroundings where there is practically no free oxygen. Yet it grows, produces energy and gets rid of waste matter. How is this brought about? The process is a remarkable one in which glycogen, the chief carbohydrate food store, is broken down without the help of free oxygen and energy is produced. It has been found that when all the water in the dead body of *Ascaris* has been removed by heating or some other means, glycogen makes up about one-third of the weight of the body substance. An organism which obtains oxygen by the decomposition of its complex food or body substance is described as anaerobic, and *Ascaris* may be compared with yeast [1] in this respect.

Since the chances of the animal food supply becoming exhausted are not very great, we do not find that *Ascaris* stores up reserve food to any extent, except in the production of eggs, in each of which a tiny food supply is provided for the developing embryo.

Waste matter is collected in two canals or tubes found one

[1] p. 253.

on either side of the body in two grooves caused by the absence of the muscular layer along these two lateral lines. The tubes are blind at the posterior end, but join at the anterior end and open by a pore on the mid-ventral surface, not far from the mouth.

When we consider the habitat of the thread-worm, we realise that eyes would not be of much use. *Ascaris* has no eyes, ears, or nostrils, but around the mouth are sensitive papillæ or swellings. These are connected by six nerves to the nerve ring or collar round the œsophagus, and from this collar, nerves pass backwards to the posterior end. The chief of these, the ventral and dorsal nerves, are connected transversely by several complete rings. *Ascaris* is therefore sensitive to its surroundings, the anterior papillæ probably acting similarly to the tentacles of a snail.

As the parasite leads a sheltered existence, dependent on its host for food and oxygen, the death of the host means the death of the parasite, so some provision must be made for the survival of the race. New individuals develop from thick-walled eggs fertilised while still in the uterus of the mother. How do these eggs reach the exterior, and how do the worms produced from them find new hosts? The eggs are shed into the intestine of the host and pass out with the waste matter. Since they are microscopic, when dry they float easily in the air so they may settle on vegetables or other food; or flies may crawl over refuse heaps, collect eggs on their bodies, and deposit them on food which may be eaten.

Other species of thread-worm live in the horse, pig, ox, cat, and dog. In all cases, the partnership of the two animals is not one of mutual benefit, for the parasite obtains its food and oxygen supply at the expense of the host, and in return gives nothing useful but probably produces substances poisonous to the host and so causes unhealthy and diseased conditions. These may in part be prevented by taking care that mouth, nose, and foods are never touched with unwashed hands. The spread of the parasite may also be checked by waging active war against the house-fly.

EXERCISES AND QUESTIONS.

1. Look for mildew on the opening buds of gooseberry and rose bushes in spring. If you find any, keep a specimen under observation and watch the changes in appearance during the formation of the summer spores and winter fruit bodies.

2. Try to find out from books on gardening and from leaflets published by the Ministry of Agriculture, the best means of keeping plants free from mildew, and how to treat those already suffering from the disease.

3. Suggest possible reasons for plants in shade being more readily attacked by mildew than those in sunny situations.

4. What are the advantages to the mildew of the formation of summer and winter spores?

5. What differences would you expect to find between parasites living inside a host and those living on its outside?

6. Describe the characters of *Ascaris* which fit it for its life as a parasite.

7. Compare the digestive system of *Ascaris* with that of the rabbit and account for the comparative difference in length of the two systems.