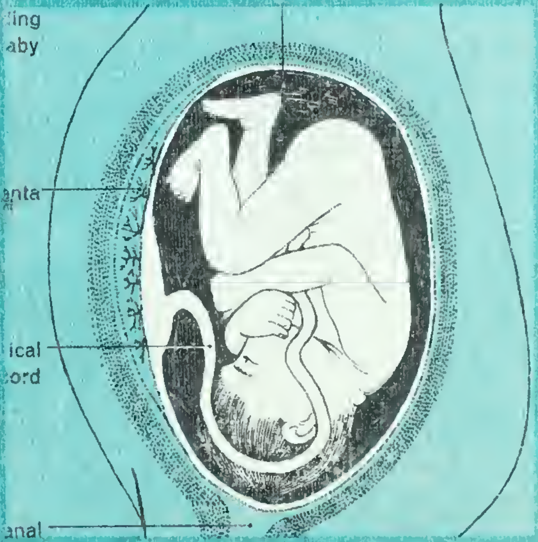
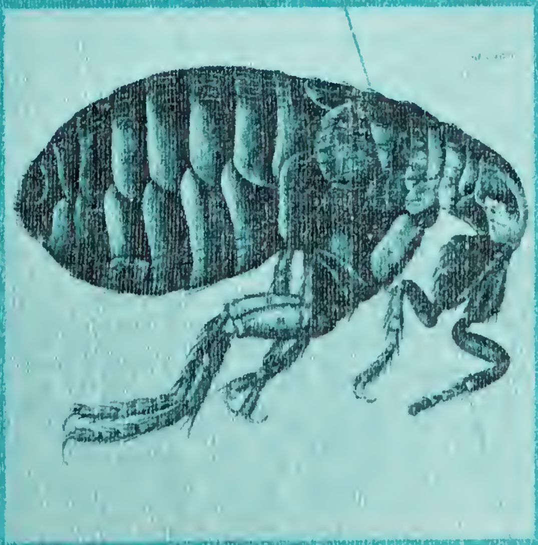
BIOLOGY

Text I *Introducing living things*





Nuffield Biology Text I **Introducing living things**

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Introducing living things

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This volume is one of the first to be produced by the Nuffield Science Teaching Project, whose work began early in 1962. At that time many individual schoolteachers and a number of organizations in Britain (among whom the Scottish Education Department and the Association for Science Education, as it now is, were conspicuous) had drawn attention to the need for a renewal of the science curriculum and for a wider study of imaginative ways of teaching scientific subjects. The trustees of the Nuffield Foundation considered that there were great opportunities here. They therefore set up a science teaching project and allocated large resources to its work.

The first problems to be tackled were concerned with the teaching of O-Level physics, chemistry, and biology in secondary schools. The programme has since been extended to the teaching of science in sixth forms, in primary schools, and in secondary school classes which are not studying for O-Level examinations. In all these programmes the principal aim is to develop materials that will help teachers to present science in a lively, exciting, and intelligible way. Since the work has been done by teachers, this volume and its companions belong to the teaching profession as a whole.

The production of the materials would not have been possible without the wholehearted and unstinting collaboration of the team members (mostly teachers on secondment from schools); the consultative committees who helped to give the work direction and purpose; the teachers in the 170 schools who participated in the trials of these and other materials; the headmasters, local authorities, and boards of governors who agreed that their schools should accept extra burdens in order to further the work of the project; and the many other people and organizations that have contributed good advice, practical assistance, or generous gifts of material and money.

To the extent that this initiative in curriculum development is already the common property of the science teaching profession, it is important that the current volumes should be thought of as contributions to a continuing process. The revision and renewal which will be necessary in the future, will be greatly helped by the interest and the comments of those who use the full Nuffield programme and of those who follow only some of its suggestions. By their interest in the project, the trustees of the Nuffield Foundation have sought to demonstrate that the continuing renewal of the curriculum – in all subjects – should be a major educational objective.

Brian Young
Director of the Nuffield Foundation

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Preface

To the pupil

You have probably been told that Biology is the study of living things. This is true but, by itself, the statement does not tell you what Biology is really about. In this course we want to do more than just teach you how living things function; we want you to understand why scientists wish to know about life and how they set about finding out biological truths.

Scientists must be curious; they must be prepared to form tentative guessing answers to the questions they ask themselves; and they must be able to test these guesses. We have tried to guide you through this process, to show you why you should be curious, what kinds of questions you should investigate and how you should devise and carry out experiments. Experiments are not intended to prove things you already know; they are to investigate whether something does or does not happen so that you can form hypotheses which, themselves, can be tested by further experiments. Thus, a negative result may be as important as a positive one. We have also tried to indicate how you should use the results you get; how you should test them further and how you should relate them to the questions you posed yourselves.

By the end of this course we hope you will know not only more about living things, particularly man, but also more about how to study living things both in the laboratory and in their natural state.

To the teacher

The essence of this Nuffield course in biology is 'science for all'. In devising it, our intention has been to provide a balanced and up-to-date view of the subject suitable for pupils who will leave school at the age of 16 and do no more formal biology. For some it will also provide a jumping-off point for further study at A-Level.

The course has been built around a number of fundamental themes. Such issues as the relationship of structure and function, adaptation and the interaction of organism and environment recur again and again in different contexts throughout the five-year period. The course is designed to foster a critical approach to the subject with an emphasis on experimentation and enquiry rather than on the mere assimilation of facts. In terms of a conventional syllabus this means that less factual matter is included. This in itself is no bad thing, provided the principles of the new teaching are accepted and the methods used are in sympathy with the aims of the course. In order to foster this outlook, a Teachers' Guide has been produced. This is closely cross-referenced to the Text and contains copious notes on teaching methods, also much technical matter relating to practical work, including additional experiments. In short, our aim has been to produce not only a new syllabus, but, more important, a new *approach to teaching*.

The course falls clearly into two parts: the first two years which can be regarded as introductory, and the remaining three which constitute the next (intermediate) phase. The introductory phase is characterized by a broad general approach to the subject. In the intermediate phase the treatment becomes more quantitative with greater emphasis on experimentation and reasoning.

At the end of most chapters of the text there is a short section entitled 'Background reading'. The topics covered relate to the preceding chapter in a variety of ways and are usually extensions of particular subjects which it has not been possible to develop fully elsewhere. This material is intended for out-of-school reading and it will not be examined in G.C.E.

In addition to the texts and guides we have produced a number of 8 mm. Film Loops for use with projectors such as the Technicolor 800 E. These are referred to at appropriate points in the guide and form an integral part of the course. They are obtainable through the same sources as the books.

Chapter 1

The variety of life

1.1 Sorting living things

Biology is the study of living things. Obviously there is no end to it. But even so it will probably surprise you to learn that living on the earth today, there are some 950 thousand different kinds of animals (just under 1 million) and about 343 thousand different kinds of plants. Clearly we need some way of dealing with such an enormous variety of living things.

Most of us like sorting things into orderly groups, just as you have probably sorted out your collection of stamps. You sort them into countries. Then you divide all those belonging to one country into groups according to their year of issue and their values.

In just the same way, biologists have tried to sort all living things into large groups and then to divide these into still smaller groups, giving every kind of plant and animal a place in the pattern of life.

You may well think all this sorting of living things is rather a waste of time. Why take so much trouble over it? If you have ever collected stamps you will be able to answer this question almost without thinking.

Suppose you were given a million stamps, some from every country in the world, and you wanted to arrange them in a collection. Some you would know at sight. Others would be strange to you and you would have to look them up in a catalogue, or a book describing all the stamps produced by every country. It is no wonder that a stamp catalogue is a large volume with several thousand pages.

Obviously it would save time if, before looking up your stamps in the catalogue, you could group together those that seemed similar in general appearance even though they were not exactly alike. For just the same reason we group together plants and animals according to their appearance and the way they live, so that it is easier to find out what they are, and to recognize them whenever we come across them.

If you were asked to make a list of all the animals and plants you could find on a country walk, how many do you think you could name? Do you think you could sort them into groups containing those kinds which appeared to be fairly alike? You might decide to sort the flowering plants that you found into different colours, or into groups with flowers of the same shape, or even according to the kind of places in which they grow.

ANIMALS WITHOUT BACKBONES

(Phyla)

Jellyfish	**Flatworms:**	**True worms**	**Arthropods**	**Molluscs**	**Starfish**
Hydra	Liverfluke	Leech		Cockle	Sea urchin
Jellyfish	Tapeworm	Earthworm		Slug	Starfish
Sea anemone	Pond flatworm	Bristle worm		Snail	Sea cucumber
Coral		Lugworm		Oyster	
				Squid	
				Octopus	
				*Ammonite	

Arthropods (Classes)

Insects	**Crustaceans**	**Spiders**	**Myriapods**
Ant	Prawn	Spider	Centipede
Glow worm	Crab	Harvestman	Millipede
Earwig	Waterflea	Scorpion	
Dragonfly	Barnacle	Tick	
Flea	Woodlouse	Mite	
	*Trilobite		

ANIMALS WITH BACKBONES (Phylum Chordata)

(Classes)

Fish		**Amphibians**	**Reptiles**	**Birds**	**Mammals**
(Gristly fish)	(Bony fish)	Frog	Snake	Swan	
Shark	Sole	Newt	Lizard	Puffin	
Dogfish	Cod	Toad	Terrapin	Eagle	
Ray	Herring	Salamander	Tortoise	Ostrich	
Skate	Eel	Axolotl	Turtle	Wren	
			Alligator	*Dodo	
			*Dinosaur		

Mammals

(Egg-laying mammals)	(Pouched mammals)	(True mammals)
Duckbilled platypus	Koala bear	Man
Spiny anteater	Opossum	Bat
	Wombat	Dog
	Flying squirrel	Hedgehog
		Whale
		Seal
		Porpoise
		*Mammoth

*Extinct animals

Table 1
The main groups of the Animal Kingdom.

THE PLANT KINGDOM

Fungi	**Algae**	**Liverworts and Mosses**	**Ferns and Horsetails**	**Conifers**	**Flowering Plants**
Moulds	Seaweed	Common liverwort	Male fern	Pine	Sycamore
Mushrooms	Some thread-like fresh-water plants	Hair moss	Hart's tongue	Fir	Snowdrop
Toadstools		Peat moss	Field horsetail	Yew	Dandelion
				Cedar	Grass
				Larch	

Table 2
The main groups of the Plant Kingdom.

ANIMALS WITHOUT BACKBONES

- **Jellyfish** Jelly-like body. Central mouth surrounded by tentacles.
- **Flatworms** Worms with flat bodies.
- **True worms** Worms with round bodies composed of rings.
- **Arthropods**
  - **Insects** Body divided into 3 parts. 3 pairs of legs. Usually 2 pairs of wings.
  - **Crustaceans** Hard outside skeleton. Jointed limbs on most body segments.
  - **Spiders** Body divided into 2 parts. 4 pairs of legs. No wings.
  - **Myriapods** Body divided into similar segments. Similar pairs of limbs to nearly all segments.
- **Molluscs** Most have either one coiled shell or two uncoiled shells. Muscular 'foot'.
- **Starfish** 5 arms, some with arms drawn up to make a round body.

Table 3
Some of the features of each group of animals without backbones.

ANIMALS WITH BACKBONES

- **Fish** Body covered with scales. Possess fins and gills. No legs.
- **Amphibians** Skin damp and naked with no scales. Four legs.
- **Reptiles** Body covered with hard scales.
- **Birds** Body covered with feathers. Two wings, Two legs.
- **Mammals** Body covered with fur.

Table 4
Some of the features of each group of animals with backbones.

PLANTS

- **Fungi** Normally possess no green colouring matter (chlorophyll).
- **Algae** Very simple plants with no root, stem or leaves.
- **Liverworts and mosses** Simple plants with no proper roots. Sometimes distinct stem and leaves.
- **Ferns and horsetails** Fibrous roots, stems and leaves. Bear spores.
- **Conifers** Trees with needle-shaped leaves. Bear cones.
- **Flowering plants** All have flowers which produce seeds.

Table 5
Some of the features of each group of plants.

Sorting all the animals and plants you find on a walk into their proper groups will, at first, be difficult, but it will become easier and easier once you have made a start.

Clearly it would be impossible to study each kind of living thing so thoroughly that we could be certain of placing it in its right group. So, to begin with, try choosing a familiar group. Look at the four birds in figure 13 for instance. Although they are of different kinds, they resemble each other in several ways and by first looking at the pictures we can make out a list of features which they all share:

a. Their bodies are covered with feathers
b. They have two legs
c. They have two wings
d. They have beaks

1.11 Sorting living things into groups

Table 1 shows the main groups of animals which together make up the *Animal Kingdom*. Underneath the headings are a few examples of each group. In the same way Table 2 shows the main groups of plants all of which belong to the *Plant Kingdom*.

At the end of the chapter you will find pictures of some animals and plants from each of the groups mentioned in these tables. Not all the groups are represented in these pictures, because many of them are small organisms which can only be seen under a microscope. We shall be studying some of these minute animals and plants later on.

Perhaps you have been collecting specimens or pictures of animals and plants for this purpose. Certainly others will have been provided for you. So now the game has really begun – the game of sorting them all into groups. This is what you should do:

1. Look at tables 3, 4, and 5. For each of these tables take a separate page in your notebook and rule columns down the page, putting in the titles of the groups at the top of each column.
2. Each specimen or picture bears a number but no name. Look at each carefully, but leave it where it is. Leave a space under the title to each column and record the number of the specimen at the lefthand side of the column to which you think it belongs.
3. When you have finished sorting the specimens and pictures, make a list, at the top of each column, of the features shared by that particular group of animals or plants. Some of these features you will find summarized in tables 3, 4, and 5. Can you think of others?

For the animals with backbones, your notebook page might look like the one facing. One of the columns in this table is partly filled out for specimen number 5 which you may think is an amphibian.

Animals with Backbones							
Fish		Amphibians	Reptiles	Birds	Mammals		
Gristly Fish	*Bony Fish*				*Egg-Laying Mammals*	*Pouched Mammals*	*True Mammals*
?	?	Skin damp and naked with no scales. Four legs (Can you think of any other features of this class ?)	?	?	?	?	?
?	?	5 ?	?	?	?	?	?

4. Later on you can go through your lists of numbers as in (*2*), adding to them the actual names of the animals and plants to which they refer.

Now look more carefully at the picture of the group to which dogs, lions, horses, and elephants belong – the mammals. You will see that whales and dolphins are included among the mammals, even though it is not true to say of these two animals that their bodies are covered with hair, or that they have four legs. How, then, can they possibly be mammals ? But look at the picture of the dolphin again and at the table giving the chief features of the mammal group, and you will see two things which you have probably not mentioned in your list: that the young of mammals are born alive and that the young are suckled with milk from the mother's mammary glands. All animals which have mammary glands and produce milk with which they suckle their young belong to the mammal group. This explains why whales and dolphins are really mammals, although they spend all their lives in the sea and their legs look like fins.

1.12 The sizes of living things

Some of the animals and plants you will look at may be preserved specimens and some will be quite small; too small, in fact, to be seen with the naked eye. So enlarged pictures of the actual specimens will be needed instead. In some cases the animals or plants are too large to bring into the classroom and so, again, they must be represented by pictures. But how small and how large are these creatures really ? On each picture at the end of the chapter the actual life size is given. We shall have more to say about size later, but for now, it is important that you should understand the signs included underneath each drawing.

If the specimen is shown at its life size then it will have the sign '$\times 1$', but for small things which have to be greatly magnified in order to be seen at all, you may see the sign '$\times$ 100', which means that the picture has been magnified one hundred times the natural size. Larger things might only need to be magnified to twice their natural size. In this case '$\times$ 2' would be the sign used. The largest specimens may be shown at half their natural size or '$\times \frac{1}{2}$', two-thirds their natural size or '$\times \frac{2}{3}$', while for very large animals, their actual size may be given. The Blue Whale, for example, is shown as '120 ft long'.

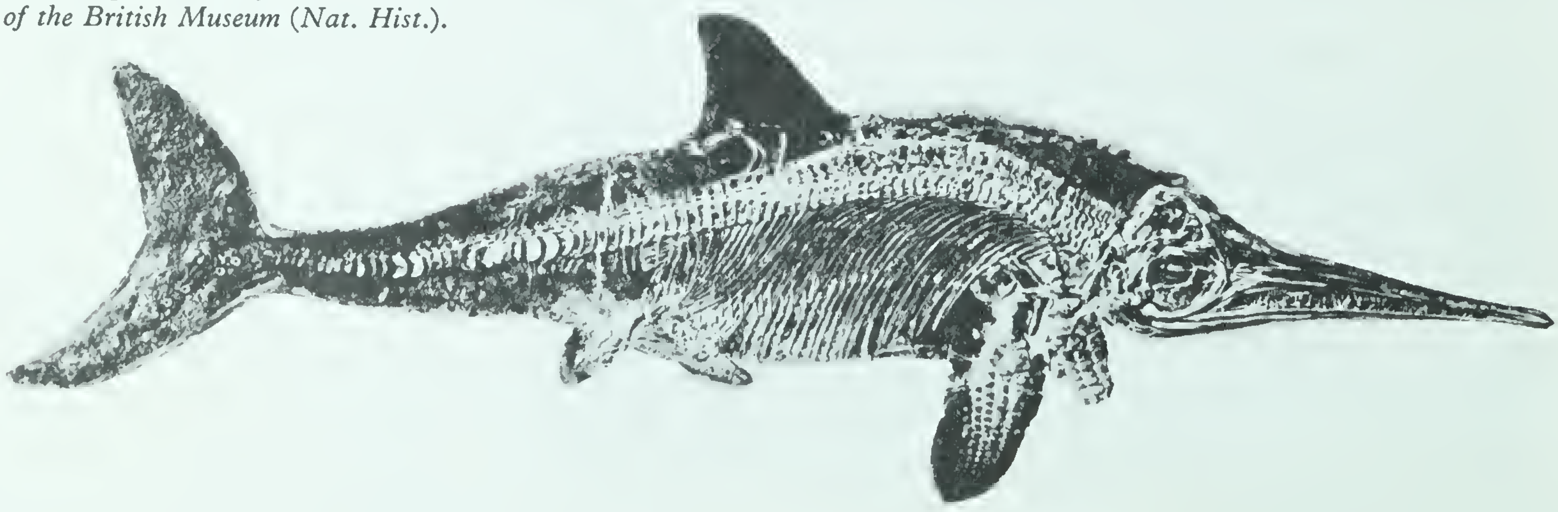
1.13 Living things which have become extinct

Table 1 shows the groups of animals arranged as a tree. Notice that those marked with a star are creatures which have become extinct; that is to say, have died out and no longer live on the earth.

You may wonder how we know about plants and animals that once lived on the earth a long time ago. When a living thing dies it usually decays quite quickly. In a short time practically nothing is left of it. But in certain places where the soil lacks air – for instance in clay – decay may be so slowed down as to come almost to a halt. In these conditions, only the soft parts of plants and animals eventually disappear. Hard pieces such as skulls, skeletons, and teeth undergo changes which preserve them against further destruction. They are then known as *fossils*, and may survive in the ground for literally millions of years.

It is, of course, possible to arrange fossil plants and animals into groups in exactly the same way as with living things. Not all soils are equally good for forming fossils. Clay is one that is particularly suitable, as you can see if you visit the Dorset coast near Lyme Regis where the cliffs are so full of fossils that they can be picked out by hand as you walk along the sea shore. Chalk also preserves things well and contains good fossils. Figures 1 and 2 show two fossil animals which are now extinct. Ichthyosaurs lived about 150 million years ago and the trilobites lived about 500 million years ago.

Figure 1
Fossil ichthyosaur $\times \frac{1}{40}$. This looks like a large fossil fish but was actually a reptile. The Ichthyosaur was about 20 ft long with a powerful tail and jaws provided with many pointed teeth. It lived in the sea about 150 million years ago and fed on fish. *By kind permission of the Trustees of the British Museum (Nat. Hist.).*



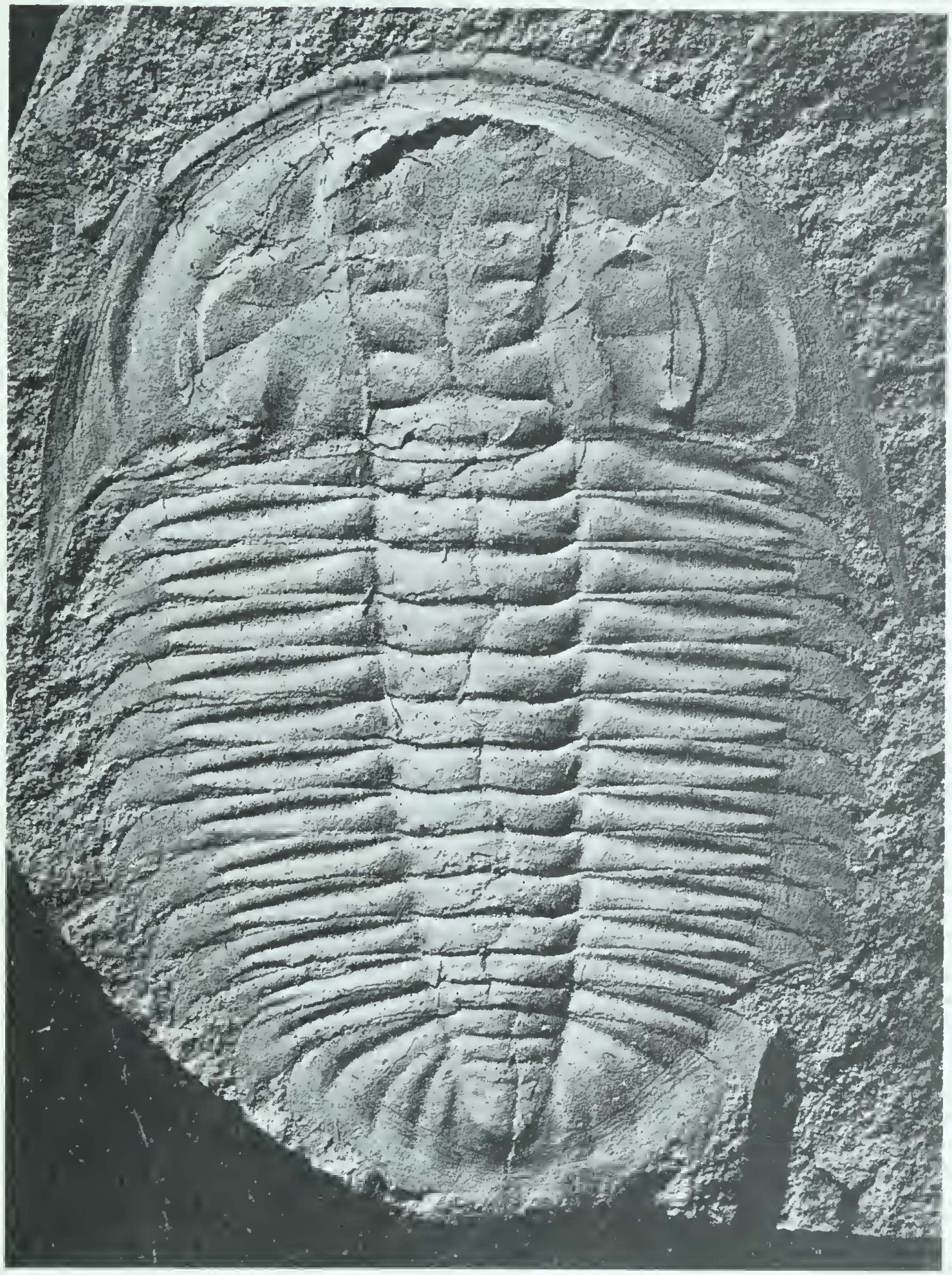


Figure 2
Fossil trilobite × 6. A crustacean which lived in the sea about 500 million years ago. Trilobites were between ½ inch and 6 inches in length. Their bodies were divided into segments which enabled them to curl up like a wood-louse. *By kind permission of the Trustees of the British Museum (Nat. Hist.).*

1.2 Classifying living things

The process of grouping is called *classification* and when we group organisms as you have been doing we are said to classify them.

The Greek philosopher Aristotle who lived more than 2,200 years ago (384 – 322 B.C.), made an attempt to classify all the animals and plants known at that time. He did this in several ways. For instance he grouped animals together according to whether they had red blood or not. But Aristotle thought that there were only a few hundred kinds of living things.

This was a very simple kind of classification and it was not until 1735, two thousand years later, that a Swedish scientist, Linnaeus, made one of the first important attempts to classify the animal and plant kingdoms. By then the numbers of animals and plants which were known had increased enormously. Nevertheless the system of classification, laid down by Linnaeus in his book which he called *Systema Naturae* (The Order of Nature) is the one which is largely used today.

Linnaeus started by giving each kind of creature two names: a name for its 'genus' which is a kind of surname, and a name for its 'species' which is a kind of Christian name. Thus the lion's scientific name is *Felis leo*. You will notice that its 'Christian name' comes *after* its 'surname' and is written with a small 'l'.

Using the idea of grouping like animals with like, let us see how Linnaeus classified the lion and fitted it into his larger groups.

Phylum	CHORDATA (Having a backbone)
Class	MAMMALS (Suckling young)
Order	CARNIVORES (Eating flesh)
Family	CATS
Genus	*Felis*
Species	*leo*

There are other species belonging to the genus *Felis* but all share the 'surname' of *Felis* and have their own 'Christian names'. Thus the domestic cat is *Felis catus*, the wild cat is *Felis silvestris*, and the tiger is *Felis tigris*.

Amongst flowers, the wild arum goes by a number of different English names. If you live in the north of England you may call it 'Devils and Angels' or 'Babes in the Wood', and you might be meaning the same flower as a friend of yours from the south of England who calls it 'Jack in the Pulpit' or 'Cuckoo Pint'. But are these flowers really the same? How can you know? For when one flower has four or five different English names you and your friend may both be talking of four or five different flowers. But if you both used the flower's proper scientific name – *Arum maculatum* – there would be no doubt.

Table 6 shows a similar classification of man (you and me), the adder, the earthworm, and the beech tree.

Table 6
Classification of man, the adder, the earthworm, and the beech tree.

Group	*Man*	*Adder or viper*	*Earthworm*	*Beech tree*
Kingdom	Animal	Animal	Animal	Plant
Phylum	Vertebrata	Vertebrata	Annelida	Spermatophyta
Class	Mammalia	Reptilia	Chaetopoda	Angiospermae
Order	Primates	Serpentes	Oligochaeta	Fagales
Family	Hominidae	Viperidae	Lumbricidae	Fagaceae
Genus	*Homo*	*Vipera*	*Lumbricus*	*Fagus*
Species	*H. sapiens*	*V. berus*	*L. terrestris*	*F. sylvestris*

1.21 Classifying living things into phyla

We have seen already that it is possible to arrange the different kinds of plants and animals in large groups having similar features. These large groups are called phyla (singular, phylum). The fact that the number of phyla in existence is quite small helps us to realize that amongst all the different kinds of living things there are only a small number of distinct patterns of structure and appearance. Some of these patterns you already know. It is, for instance, quite easy to say whether a particular animal is an insect or a starfish. Insects all have the same general appearance and therefore belong to the same phylum: all starfish, on the other hand, have the same general pattern of structure and thus belong to another phylum.

A phylum, therefore, is made up of a number of plants or animals which, although not exactly alike, are built upon the same general plan, just as bicycles resemble each other but differ from motor cars. Altogether there are about twenty main phyla of living things.

While the animals without backbones are divided into a number of separate phyla, those with backbones belong to one big phylum. When a phylum is as large as this it becomes necessary to divide it into smaller groups called classes. Thus the Vertebrates are divided into five classes:

Phylum VERTEBRATES

Class 1	Class 2	Class 3	Class 4	Class 5
FISHES	AMPHIBIANS	REPTILES	BIRDS	MAMMALS

Again it is necessary to divide classes into smaller groups (orders), orders into families and families into genera (singular genus). Finally, each genus is divided into species (singular species) – the smallest group of all.

1.22 Dividing a phylum into classes

We can now try out a slightly more detailed sorting of a large group into smaller ones. Let us classify some of the animals belonging to the phylum Arthropoda (Greek: *arthron* = joint; *pous* = foot) into the four classes comprising the phylum.

Here is a table showing how the phylum Arthropoda is divided (see table 7). To help you, some information is given with the title of each class.

Phylum Arthropoda			
Insects (Class Insecta)	Crustaceans (Class Crustacea)	Spiders (Class Arachnida)	Millipedes and Centipedes (Class Myriapoda)
Body divided into 3 parts 3 pairs of legs Usually two pairs of wings	Very hard outside skeleton Jointed limbs on most body segments	Body divided into 2 parts 4 pairs of legs No wings	Body divided into many similar segments Similar pairs of limbs attached to nearly all segments

Table 7
The classes of arthropods and the chief features of each class.

Using the information in table 7 try to sort out a collection of animals into these four classes of arthropods.

1. Head a page of your notebook 'phylum Arthropoda' and divide the page into four columns, putting the name of a class at the head of each column.
2. Each specimen or picture bears a number but no name. Look carefully at each, but leave it where it is. Leave a space under the title to each column and record the number of the specimen at the lefthand side of the column to which you think it belongs. The pictures in figure 7 may help you.

The page you prepare in your notebook may look like the one below which has one of the columns partly completed for specimen number 4 which you might think belongs to the Crustaceans.

Phylum Arthropoda			
Insects	Crustaceans	Spiders	Millipedes and Centipedes
?	Hard outside skeleton. Jointed limbs on most body segments. (Can you think of any other features of this class?)	?	?
?	4 ?	?	?

3. When you have finished sorting all the specimens and pictures make a list at the top of each column of the features which you think are typical of that particular Class. Some of these features you will find included in table 7. Can you think of others?
4. Later on you can go through your lists of numbers, adding to them the actual names of the animals to which they refer.

You will probably find that your list of insects is much longer than all the others, while that of centipedes and millipedes is quite short. If you look at the diagram in figure 3 you will see that it shows as a segment of the circle, the numbers of animals known in each of the classes of the phylum Arthropoda, each segment being in proportion to the numbers of species of animals in that class. There are only about 8,000 known species of Myriapoda (Greek: *Myrias* = ten thousand; *pous* = foot), but about 722,000 known species of insects in the world. This, perhaps, explains why your list will be longer for insects than for millipedes and centipedes (Myriapoda). You will also notice that there are more crustaceans than spiders, which belong to the Arachnida (Greek: *arachne* = spider, *oidos* = form).

Figure 3
The numbers of species in the different groups of the Animal Kingdom, shown as segments of a circle.

Look again at the specimens provided, and try to answer these questions:
a. Can you see any features which are shared by all the members of the phylum Arthropoda?
b. Can you suggest any other ways in which spiders are different from insects?

The Animal Kingdom

Animals without backbones

(Invertebrates)

Soft jelly-like body, which is arranged on a circular plan.

Usually a central mouth surrounded by a ring of tentacles, but with no proper head.

Figure 4
JELLYFISH
(Phylum Coelenterata)

a. A coral colony × 1

b. Dahlia anemone × $\frac{2}{3}$
Tealia felina.

c. Brown jellyfish × $\frac{1}{8}$
Chrysaora isosceles.

d. Green *Hydra* × 6
Hydra viridissima.

All live in water and most live in the sea, although some, like *Hydra*, are freshwater animals.

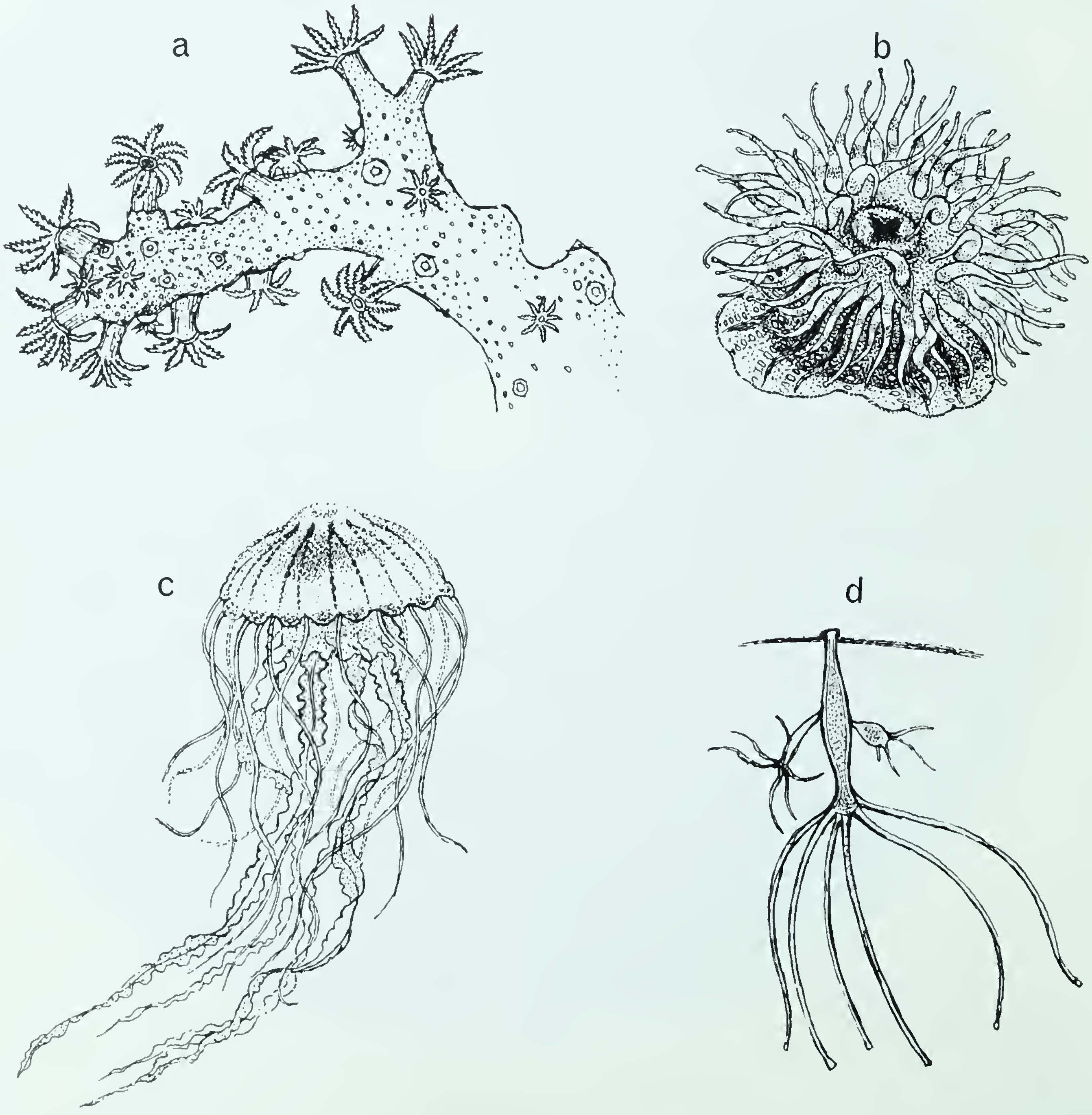


Figure 5
FLATWORMS
(Phylum Platyhelminthes)

a. Tapeworm × 1
Taenia solium.

b. Marine flatworm × 2
Prostheceraeus vittatus.

Many live in fresh water under stones. A few live on the shore under stones, like the marine flatworm.

Many are parasitic, like the tapeworm, and live inside other animals. They have a complicated life history.

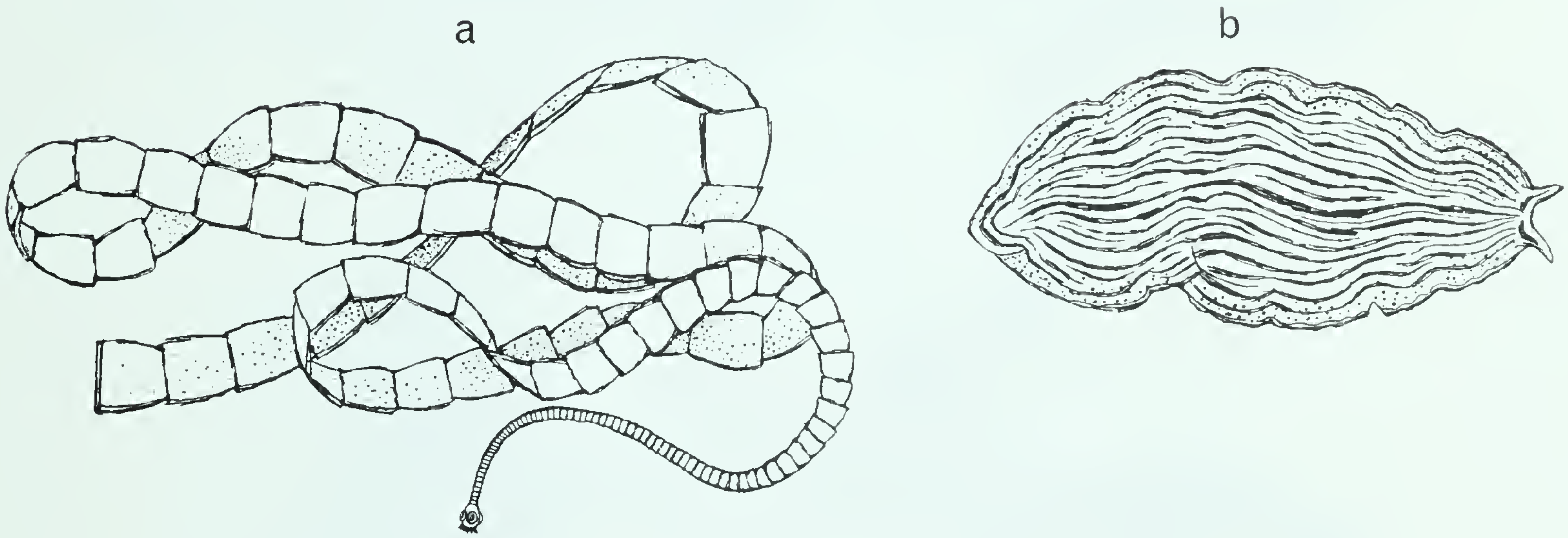


Figure 6
TRUE WORMS
(Phylum Annelida)

a. Common earthworm $\times \frac{2}{3}$
Lumbricus terrestris.

b. Horse leech $\times \frac{2}{3}$
Haemopsis sanguisuga.

c. Marine bristle worm $\times 1\frac{1}{2}$
Nereis diversicolor.

d. Peacock worm $\times \frac{2}{3}$
Sabella pavonina.

Many live in the soil or in fresh water. Some live on the shore under stones, or inside tubes of sand which they make (like the marine bristle worm and the peacock worm).

All have their bodies divided into rings, often bearing tufts of chaetae, but they have no arms or legs.

Leeches are mostly found in fresh water and have a sucker at each end of the body. For part of their lives they may be parasites sucking the blood of the animal to which they cling by their suckers.

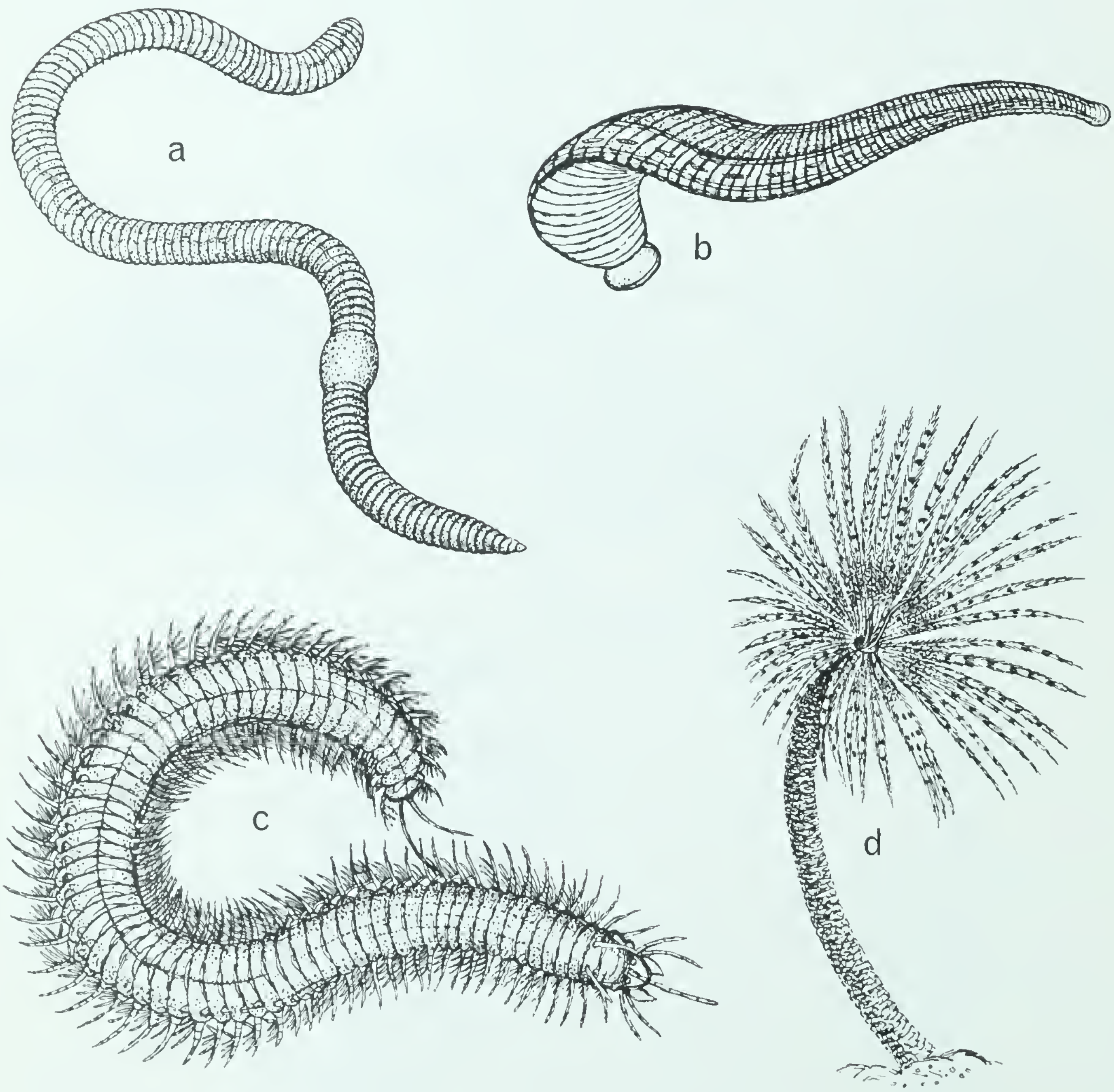


Figure 7
ARTHROPODS
(Phylum Arthropoda)

a. Dragonfly × 1
Aeschna viridis.

b. Shore crab × ½
Carcinus maenas.

c. Wolf spider × 2
Lycosa sp.

d. Centipede × 1
Lithobius forficatus.

e. Millipede × 1
Iulus terrestris.

A very large group which has to be divided into four smaller groups.

All have a hard outside skeleton and shed this outer covering as they grow larger.

All have jointed bodies and jointed legs.

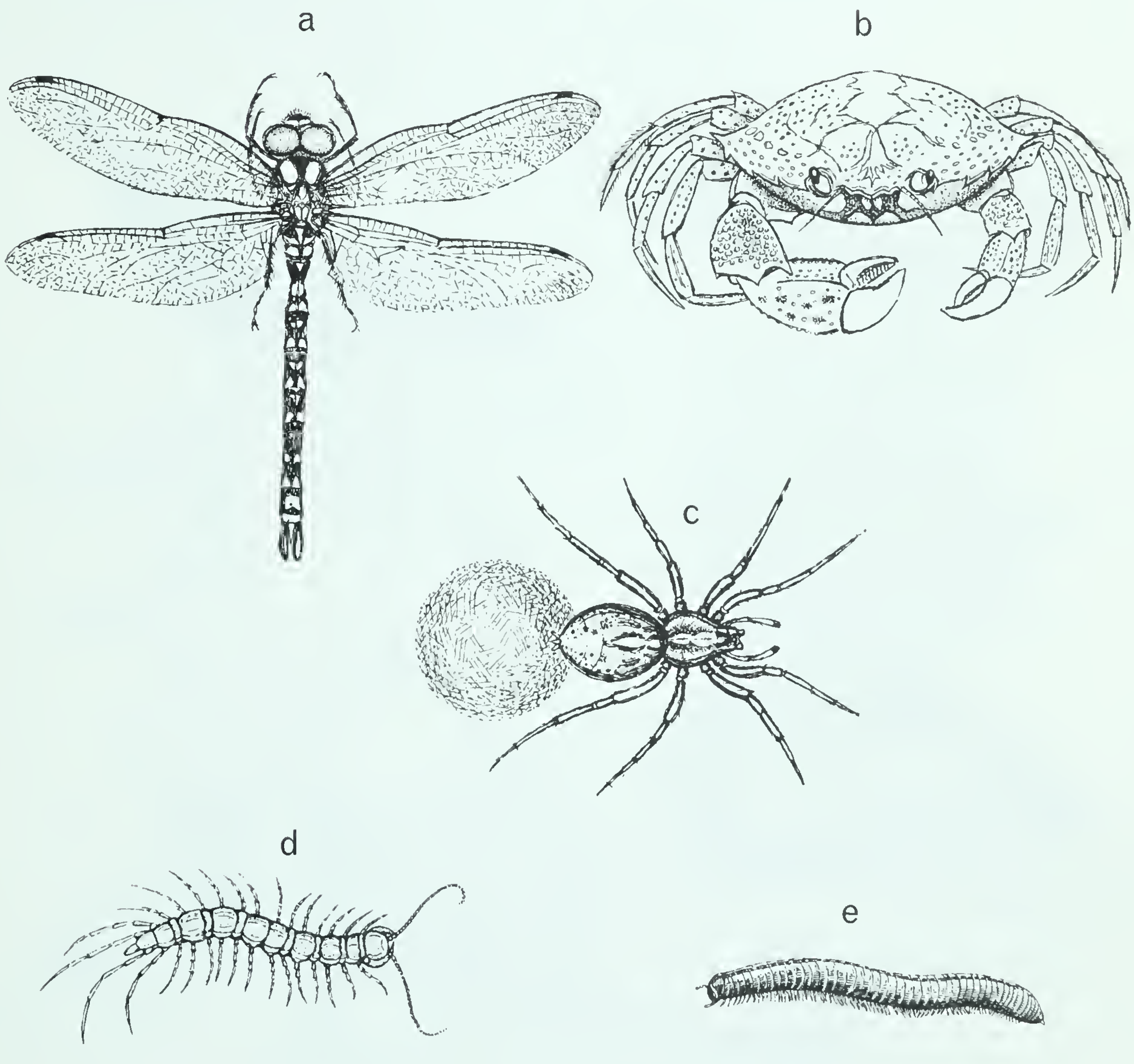


Figure 8
MOLLUSCS
(Phylum Mollusca)

a. Garden snail × 1
Helix aspersa.

b. Black slug × $\frac{2}{3}$
Arion ater.

c. Common mussel × 1
Mytilus edulis.

d. Common octopus × $\frac{1}{4}$
Octopus vulgaris.

Some are found on the land. But most live in the sea or in fresh water.

Nearly all possess either one coiled shell like the garden snail, or two shells like the common mussel. Some have no shell at all, like the octopus.

Most have a muscular foot which they use for crawling.

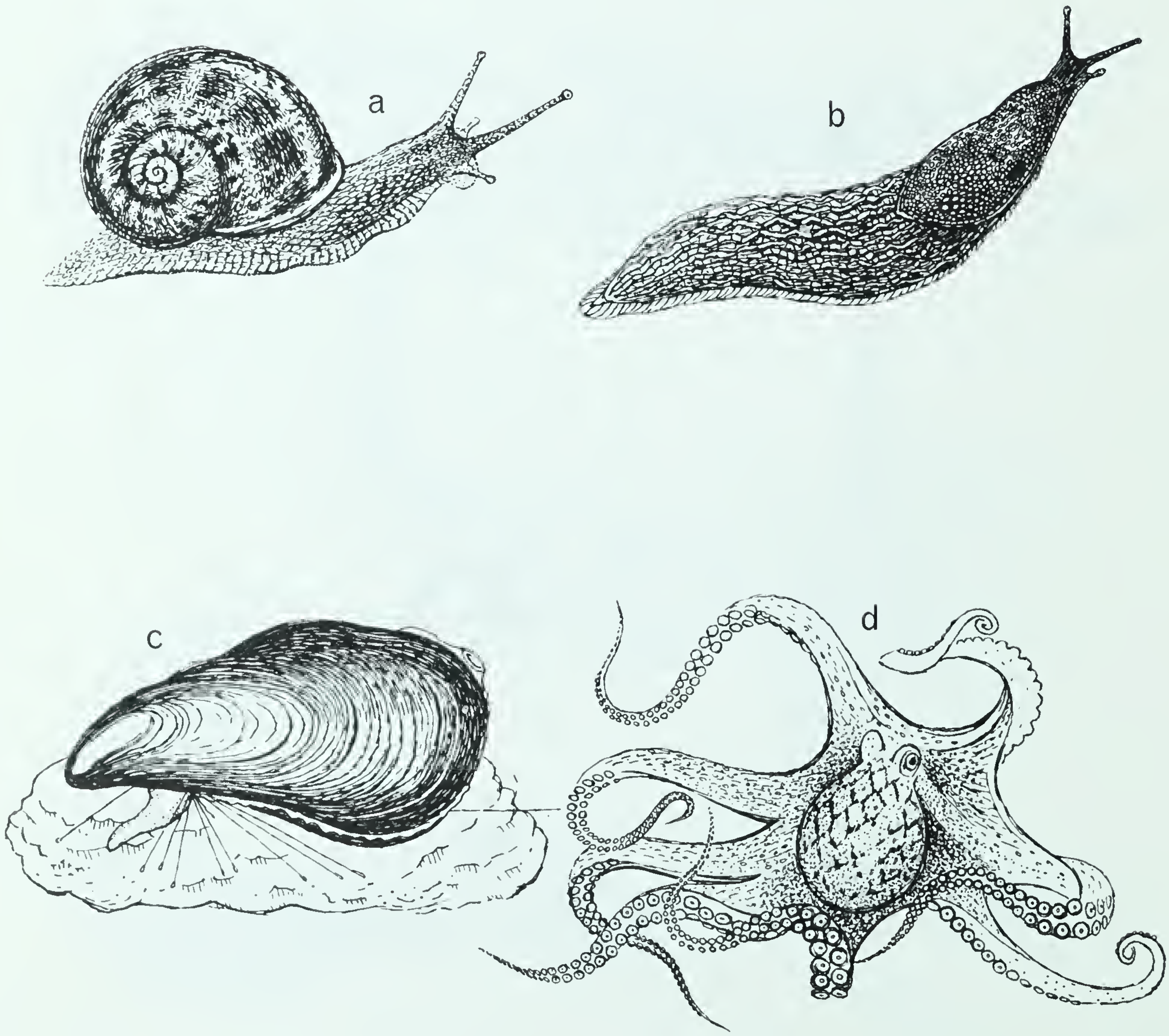


Figure 9
STARFISH AND SEA URCHINS
(Phylum Echinodermata)

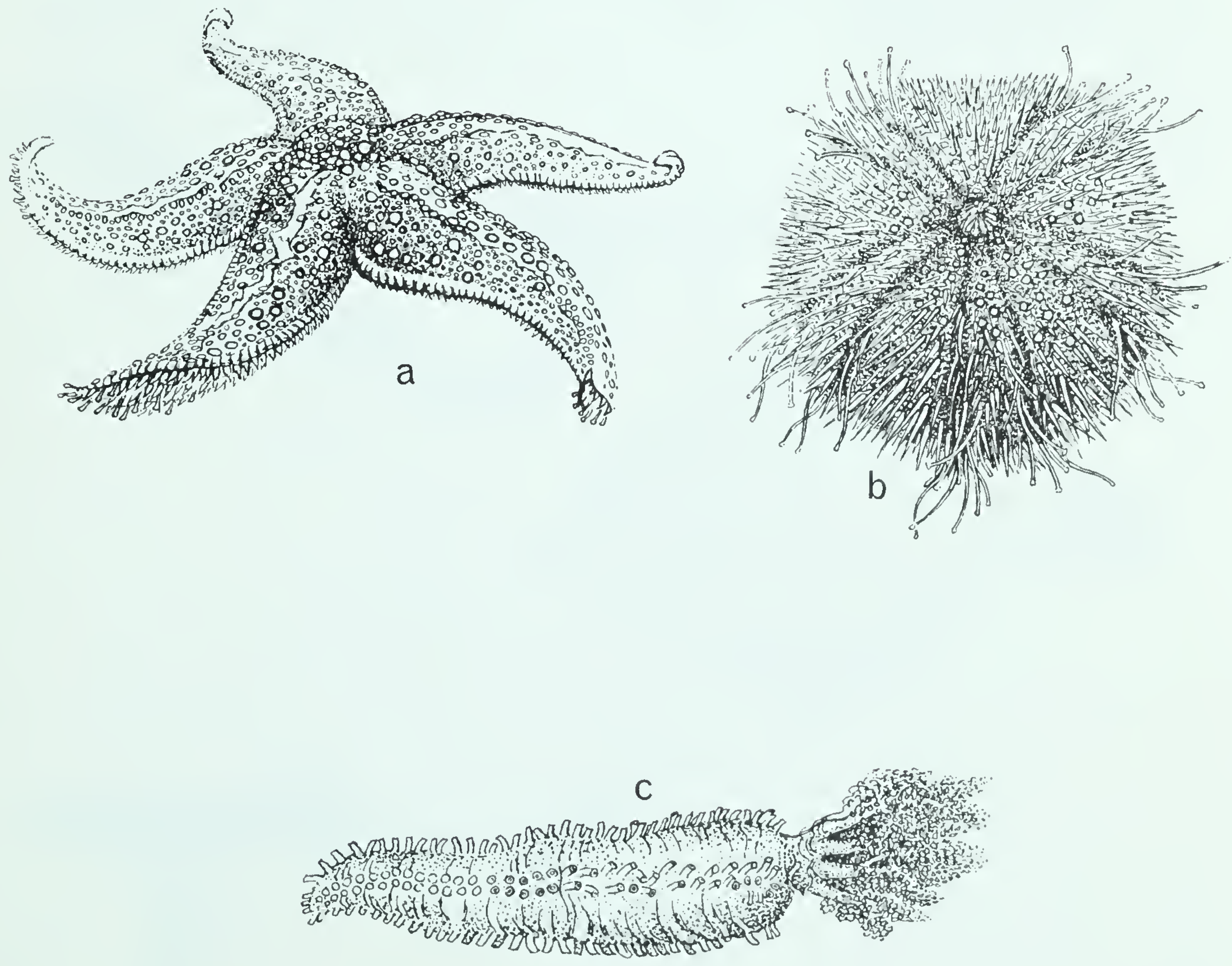
a. Common starfish $\times \frac{2}{3}$
Asterias rubens.

b. Common sea urchin $\times \frac{1}{2}$
Echinus esculentus.

c. Sea cucumber $\times$ 1
Cucumaria saxicola.

All members of this group live in the sea.

Their bodies have five arms and are arranged on a circular plan. The sea urchins and sea cucumbers have the five arms drawn up to make a round body.



Animals with backbones
(Vertebrates)
(Phylum Chordata)

Figure 10
FISHES
(Class Pisces)

a. Mackerel; up to 18 in
Scomber scombrus.

b. Conger-eel; up to 8 ft
Conger conger.

c. Plaice; up to 2 ft
Pleuronectes platessa.

d. Blue shark; up to 25 ft
Prionace glauca.

All live in the sea or in fresh water.

Their bodies are covered with scales.

They have a definite head, body, and tail.

They move by means of fins.

Most lay eggs without shells which are covered with jelly.

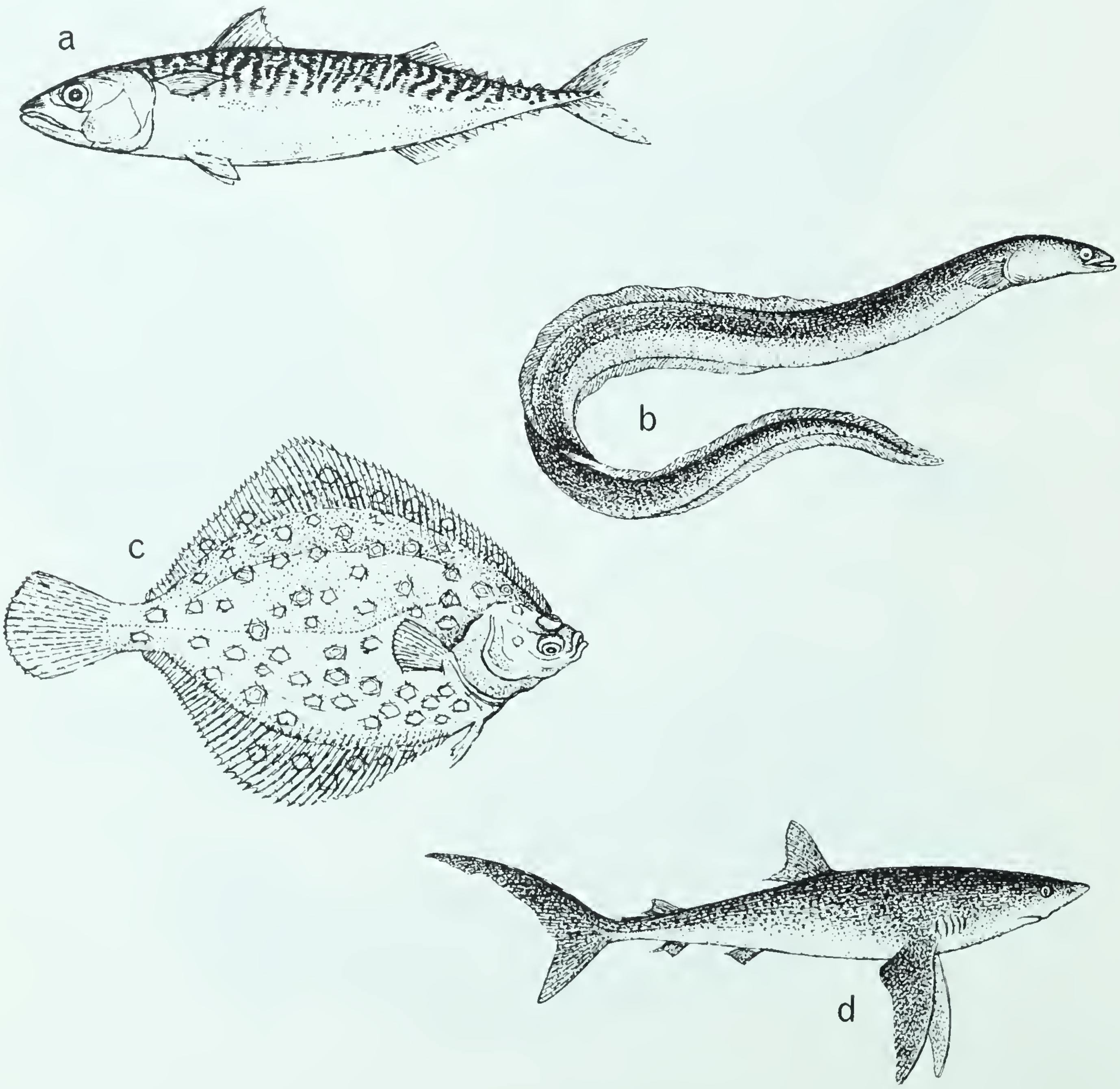


Figure 11
AMPHIBIANS
(Class Amphibia)

a. Common frog × ½
Rana temporaria.

b. Natterjack toad × ⅔
Bufo calamita.

c. Smooth newt × ⅔
Triturus vulgaris.

They live on land and in fresh water but must lay their eggs, covered in jelly, in water.

Skin damp and naked with no scales.

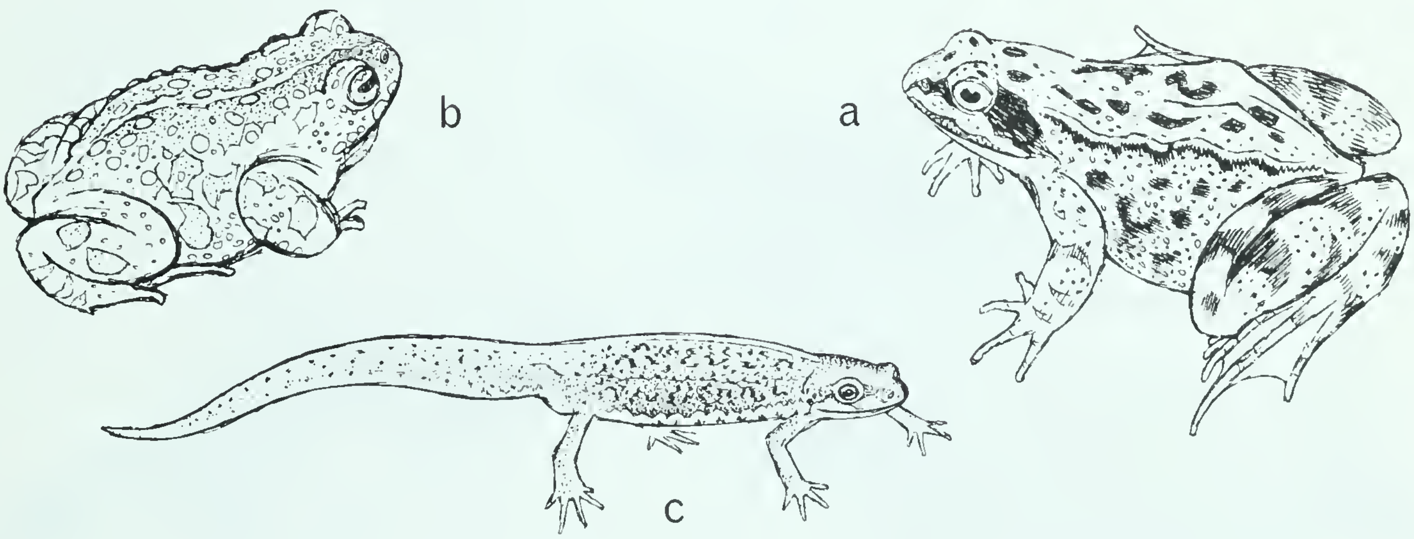


Figure 12
REPTILES
(Class Reptilia)

a. European terrapin × ½
Emys orbicularis.

b. Common lizard × 1
Lacerta vivipara.

c. Adder; up to 34 in.
Vipera berus berus.

They mostly live on land, although some, like crocodiles, alligators, and terrapins live in, or near rivers or ponds. Some, like turtles, live in the sea.

All have bodies covered with scales and must lay their soft-shelled eggs on land.

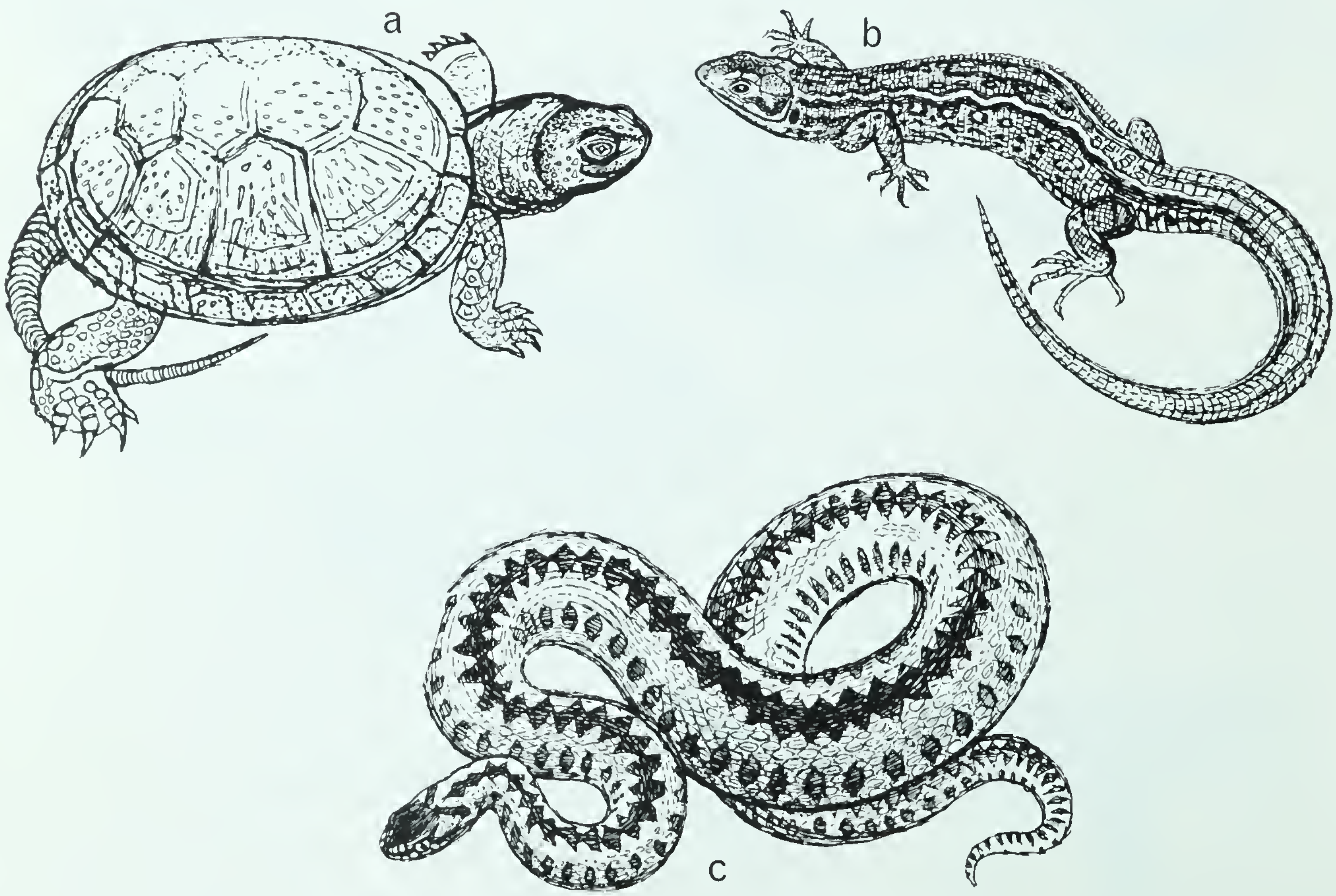


Figure 13
BIRDS
(Class Aves)

a. Long-eared owl; about 14 in
Asio otus otus.

b. Penguin; about 1 ft
Aptenodytes patagonica.

c. Song thrush; about 9 in
Turdus musicus

d. Humming bird × 1
Selaphorous sasin.

All possess wings, which are really the front legs, with which they fly (although the penguin and some other birds have lost the power of flight).

All have bodies covered with feathers.

All lay eggs with hard shells.

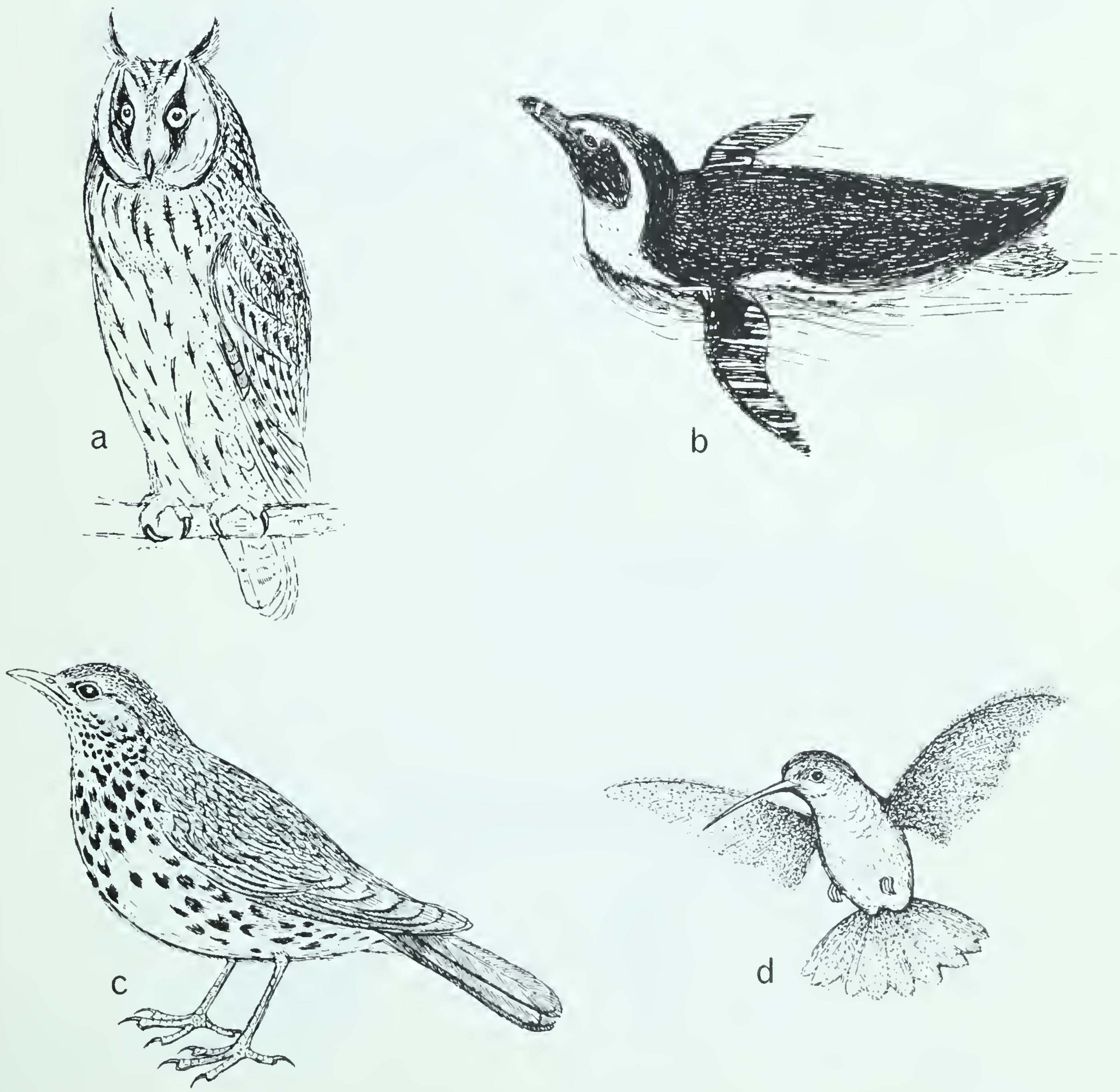


Figure 14
MAMMALS
(Class Mammalia)

a. Man; 6 ft tall
Homo sapiens.

b. Lion; 7 ft
Felis leo.

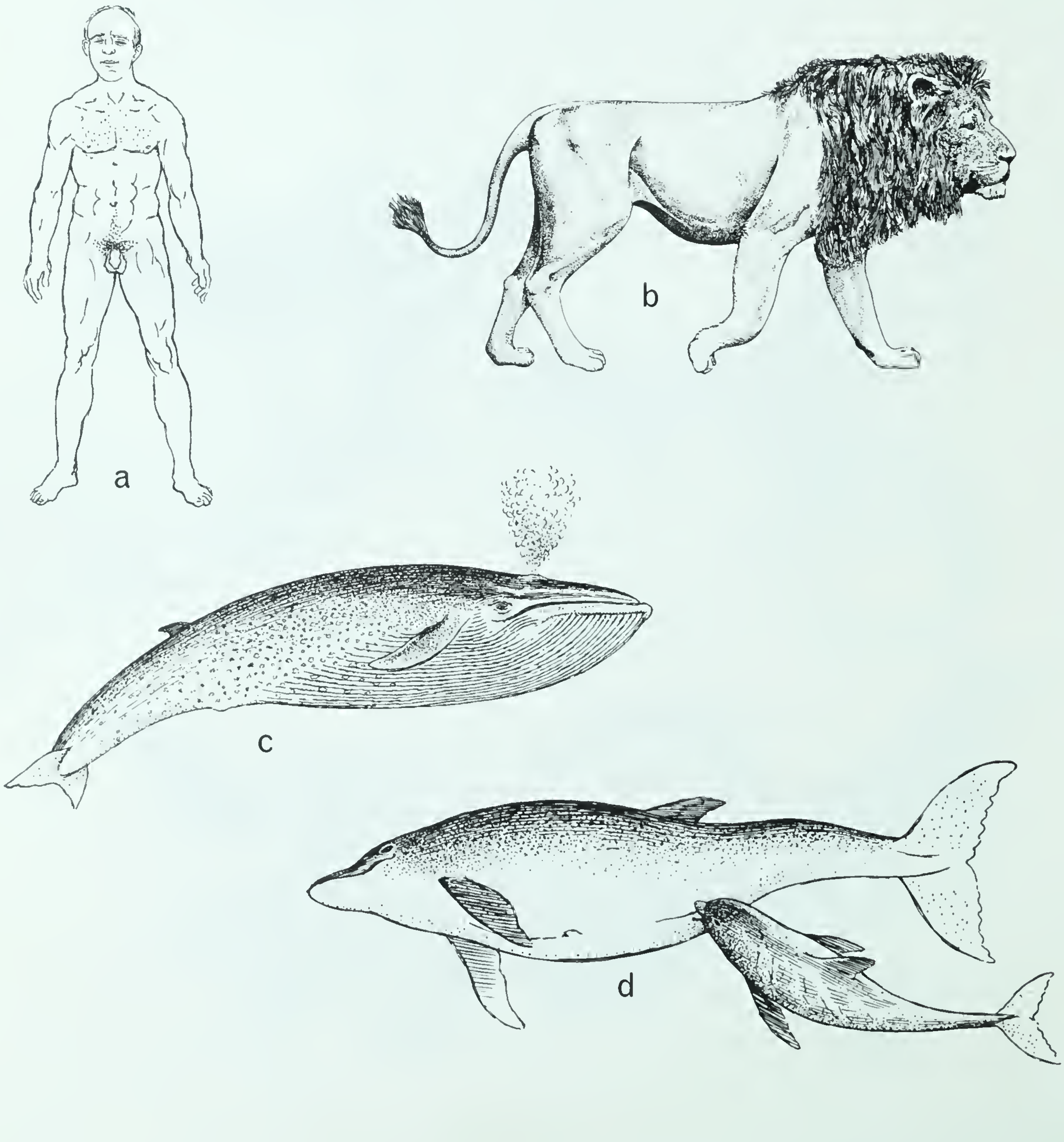
c. Blue whale; 120 ft long
Balaenoptera musculus.

d. Common dolphin; up to 12 ft long
Delphinus delphis.
(*Marineland of Florida.*)

All (except whales, dolphins, and porpoises) have their bodies covered with fur.

All have young born alive (except the duckbilled platypus and the spiny anteater, which lay eggs) and the young are suckled from mammary glands.

Most have sweat glands.



The Plant Kingdom

Figure 15
FUNGI

a. Pin mould × 25
Mucor sp.

b. Fly agaric toadstool × $\frac{1}{2}$
Amanita muscaria.

c. Birch bracket fungus × $\frac{1}{4}$
Polyporus betulinus.

Fungi are not true plants. They are normally never green; a few possess green pigment which is not the same as that of true plants (chlorophyll). Thus they are unable to make their own food like plants. Many are parasitic on other plants and some on animals also.

They vary in size from microscopic moulds to the large bracket fungi found on trees and the giant puff balls of grassland.

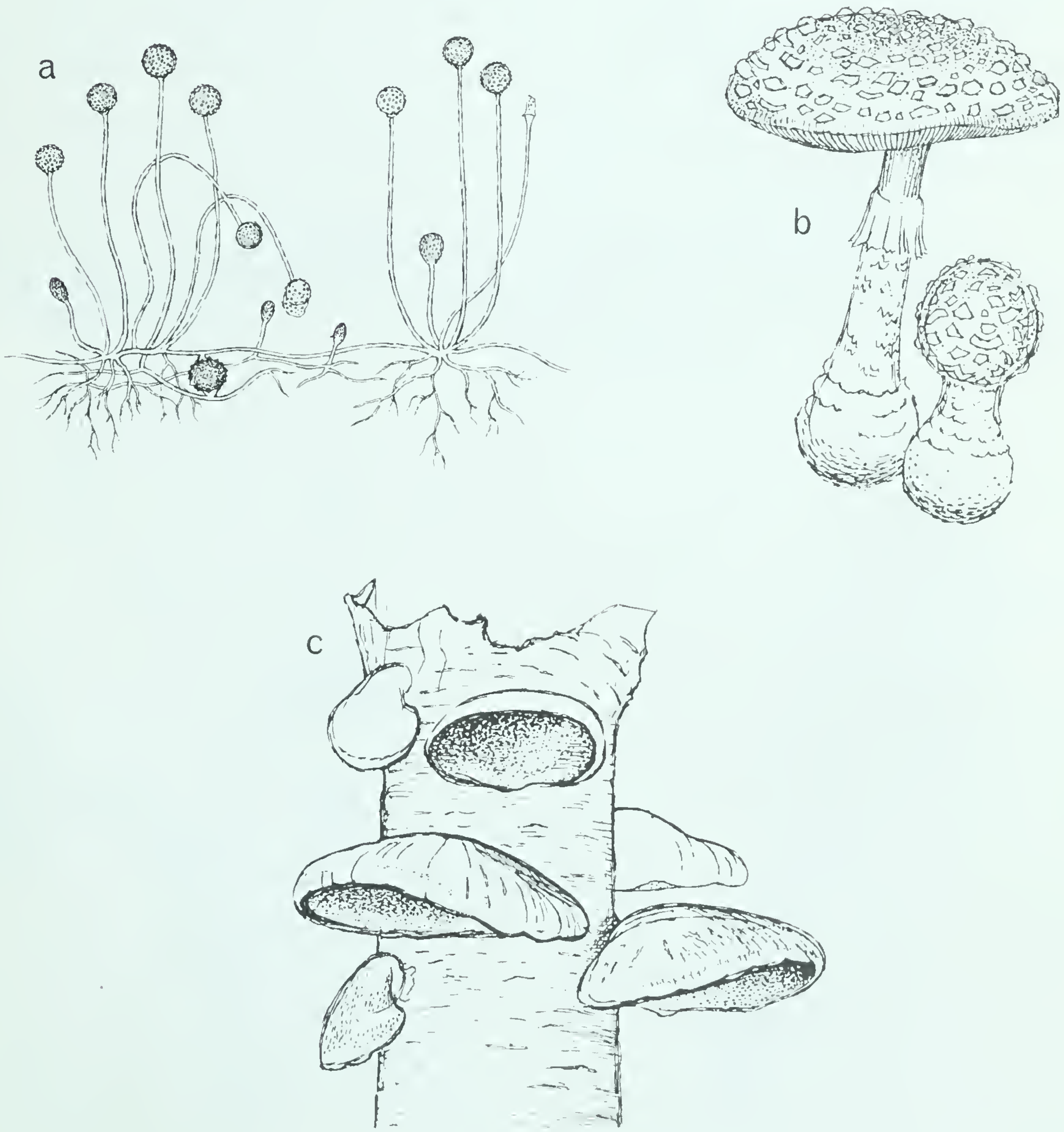


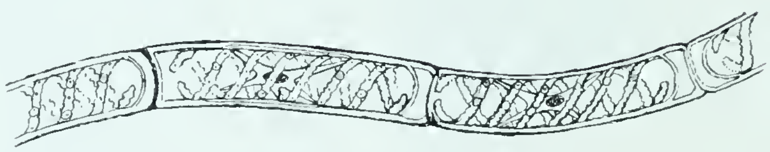
Figure 16
ALGAE
(Phylum Thallophyta)

a. Microscopic green alga × 35
Spirogyra sp.

b. Seaweed × ½
Fucus vesiculosus.

Many are microscopic plants, living in the sea, fresh water, or even in the soil. Some are much larger, like the brown, green, and red seaweeds of the shore. None have proper roots, stems, or leaves.

a



b

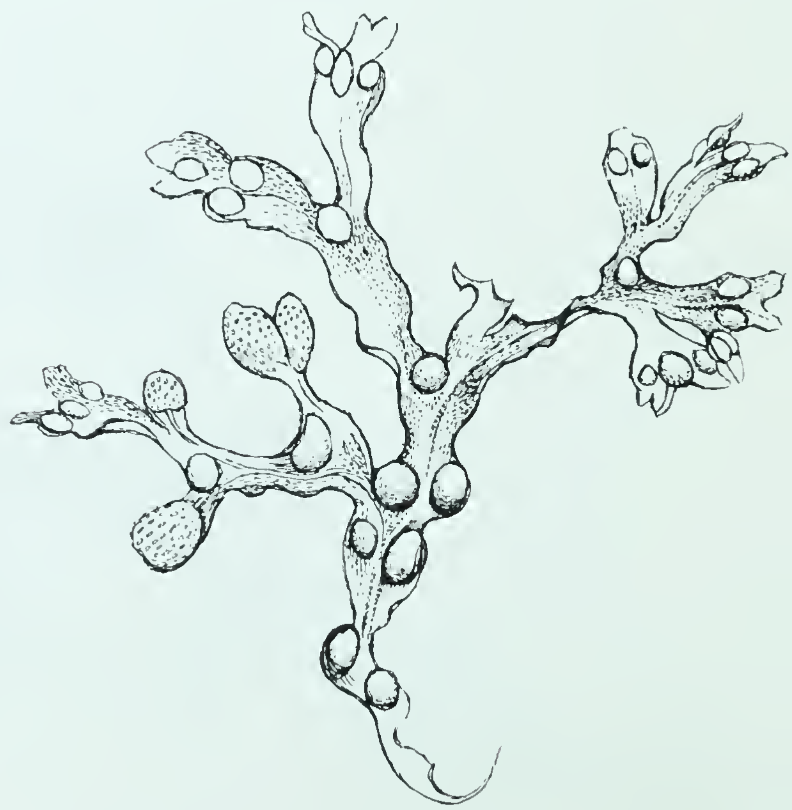


Figure 17
MOSSES AND LIVERWORTS
(Phylum Bryophyta)

a. Liverwort × 1
Marchantia polymorpha.

b. Common hair moss × $\frac{2}{3}$
Polytrichum commune.

They are all green plants but live on land, usually in damp places.

Liverworts have a flat kind of leaf, with no rib down the centre.

Mosses have proper leaves, often very small, with a midrib. Look for upright stems with little capsules at the end.

Some mosses and liverworts are very difficult to tell apart without close examination using a hand lens.

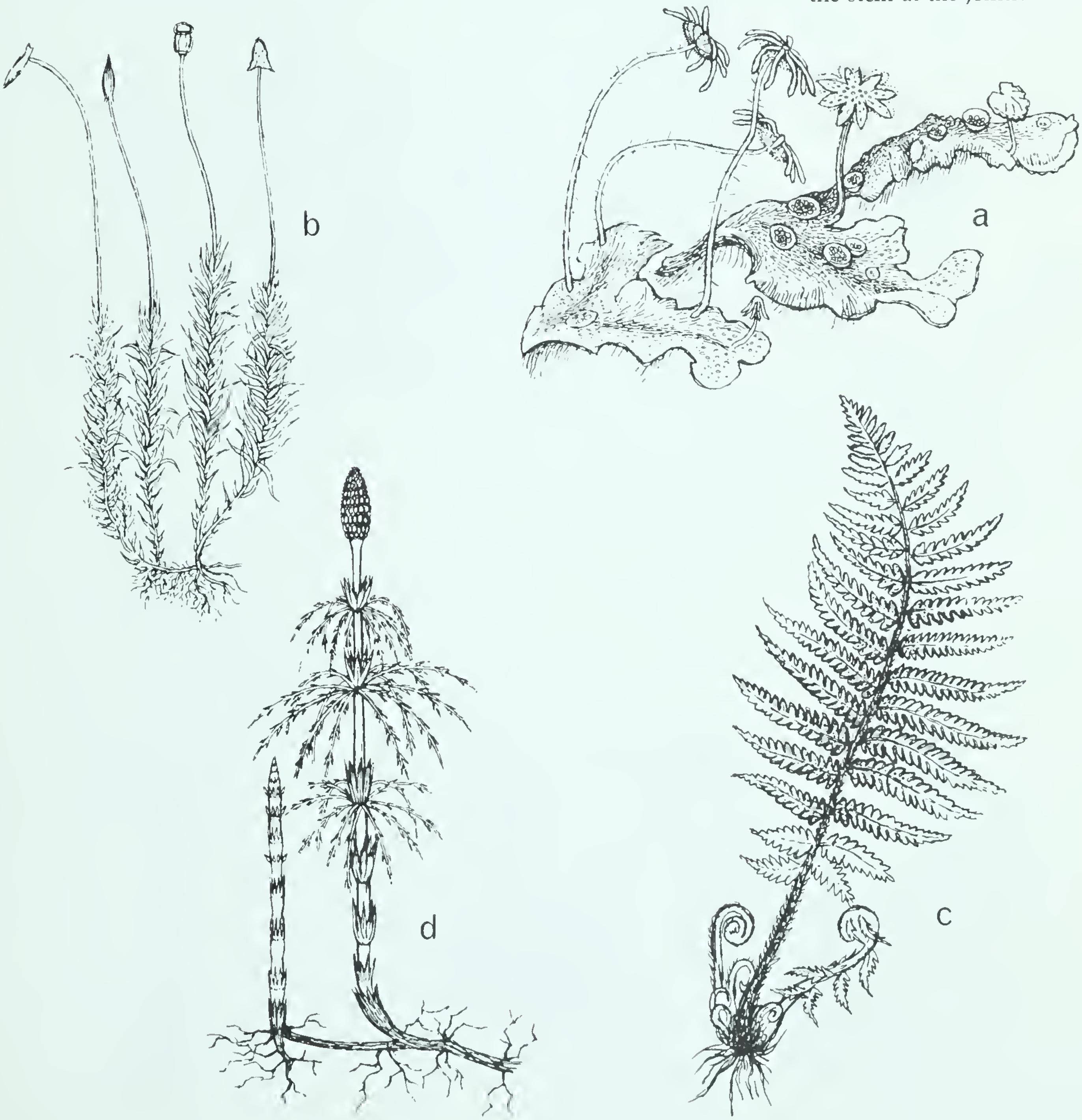
FERNS AND HORSETAILS
(Phylum Pteridophyta)

c. Male fern × $\frac{1}{4}$
Dryopteris filix-mas.

d. Woodland horsetail × $\frac{1}{4}$
Equisetum sylvaticum.

Ferns grow in damp, shady places and have much-divided fronds growing from a thick woody stem near ground level. Look at the backs of the leaves for the little groups of brown spores.

Horsetails grow in very damp places and have stiff, upright, jointed stems with whorls of spiky leaves arranged in a circle round the stem at the joints.



26 Plants which make seeds

(Phylum Spermatophyta)

Figure 18

THE CONIFERS
(Sub-phylum Gymnospermae)

a. Branch of Scots pine tree
Pinus sylvestris.

Trees with needle-shaped leaves and bearing cones. Look inside the scales of the cone for the seeds. Cone-like flowers which are not like ordinary flowers.

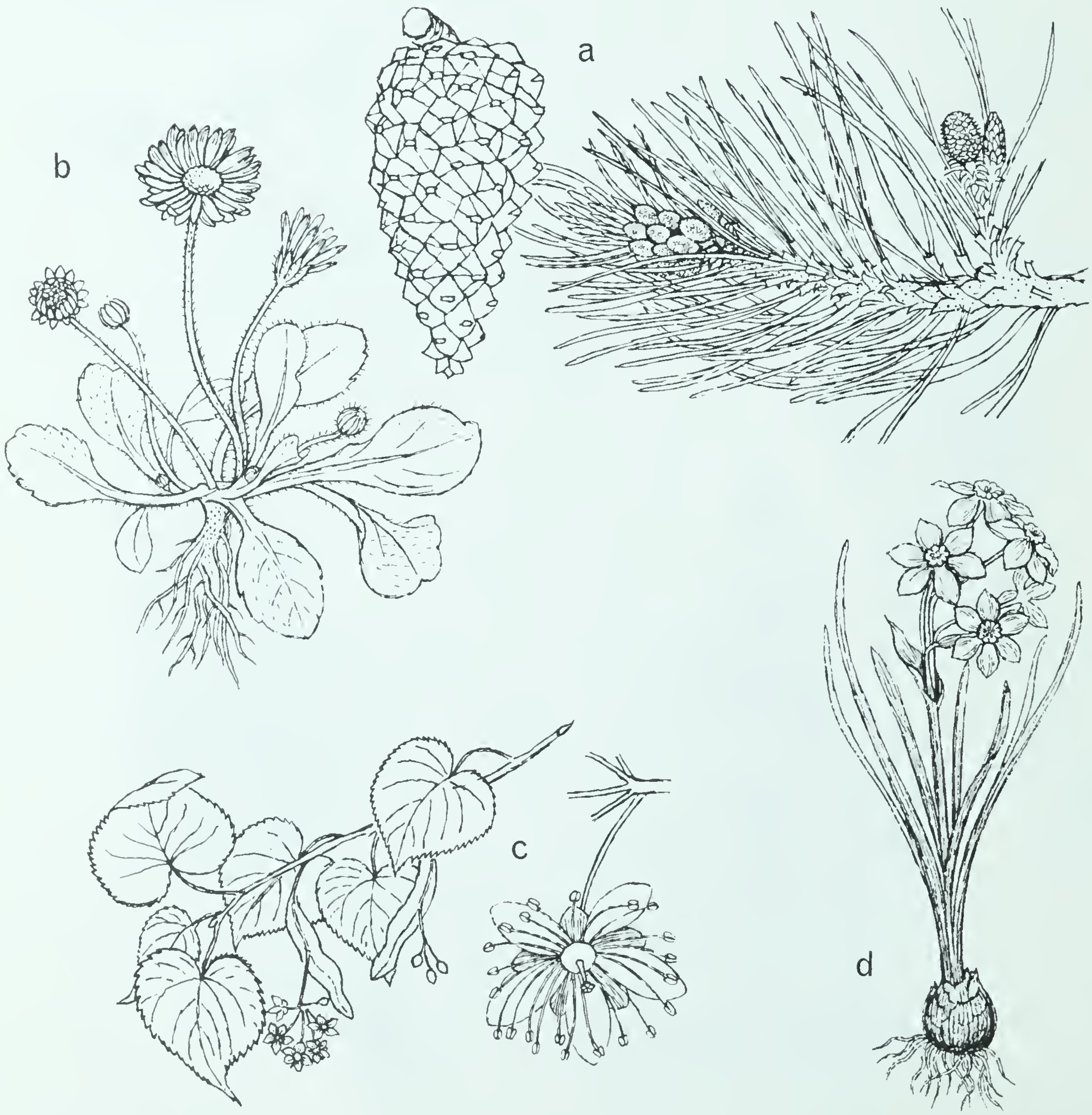
THE FLOWERING PLANTS
(Sub-phylum Angiospermae)

b. Daisy
Bellis perennis.

c. Branch of common lime tree
Tilia europea.

d. Narcissus
Narcissus sp.

Some are trees, some are very small plants growing near the ground, but all have flowers and produce seeds. Grasses are also flowering plants.



Summary

In this chapter we have tried grouping living things together according to whether they look alike. The purpose of this is to make it easier to name them so that we – and anyone else – can recognize them next time they turn up. We have seen that there may be exceptions to what look like simple rules. But then biology is full of exceptions, although there is always a reason for each. If everything followed the rules, life itself and learning about life, would be a dull affair.

Every living thing is given two names, a 'surname' and a 'Christian name' (genus and species) written in Latin, the universal language of biologists. By using the correct scientific name we can avoid all misunderstanding. Indeed, we find there are so many plants and animals which have no English names, that we have got to use the Latin one.

Many thousands of new species of animals and plants have been discovered and named since the days of Linnaeus and each has been given a place in the system of classification.

Background reading

Making a Collection

Towards the end of last century it was the fashion for people to make collections of all kinds of things – shells, fossils, dried plants, insects, and even birds' eggs. Some of the largest collections housed in our museums today date from this period. There is nothing wrong in collecting things; indeed, the purpose of this short account is to encourage you to make collections of your own. But before starting out to make a collection we must ask ourselves this important question – what is it for? This is the question that our Victorian ancestors frequently failed to answer. The result was all too often a mass of unclassified specimens lining the drawers of endless cabinets and providing little information about the specimens themselves. This was hoarding, not collecting. When we collect we must do so for a purpose – to gain knowledge about the things we collect.

Nowadays we no longer collect birds' eggs. This is partly because we know that by doing so we may seriously reduce the numbers of birds, but also because the lives of birds can be better studied in other ways. Thus, with the aid of a pair of field glasses (or even without them), we can learn far more about birds and their nesting habits by watching them build their nests and rear their young unmolested than by hoarding their eggs in a cabinet. What is true of birds is also true of all other animals, and plants as well.

There are so many different kinds of living things that at first it may seem difficult to know how best to begin studying them. Probably one of the easiest ways of doing so is to start collecting in a small way, confining your search to particular places such as an oak wood or a meadow or even to animals living under stones or in a pond. Later on, perhaps when you go on holiday, you may be able to collect in similar places in other parts of the country. Or you might start a collection of things from a new kind of area, such as the seashore.

In making collections from different places you will soon discover that certain plants and animals live in some localities and not in others, that you can find them only at certain times of the year and that they have various ways in which they protect or conceal themselves. Indeed collecting helps us to make all kinds of observations about the animal or plant in its natural surroundings while it is alive.

In order to collect living things certain equipment is necessary but exactly what you need will depend upon the kind of things you intend to collect. Here, we can only mention a few things most of which can easily be made or found at home.

A hand lens, for instance, is indispensable – one that magnifies eight times is the best. Then you will need containers in which to put your finds. Polythene bags are best for plant collecting since the plants will remain fresh if you keep the bag closed. Tins of various sizes are useful for both sea and freshwater specimens. Sea fish and molluscs travel best packed in seaweed; and freshwater fish and other animals, in pondweed with a little water in the bottom of the tin. Corked plastic tubes of different sizes (glass ones are easily broken) can take smaller specimens. Insects are best killed in a killing bottle which can be made from a screw-top honey jar in the bottom of which is a $1\frac{1}{2}$ inch layer of chopped and tightly packed cherry laurel leaves. When dead, they can be transferred to paper envelopes.

Always attach a number to each specimen as you collect it. A note in your fieldbook (which you should carry with you) against the number of the specimen, should record where you found it, the date, and any other interesting things such as the animals and plants with which it was associated. Then, when you are ready to put your find into a collection you can write the information on its proper label.

One of the greatest difficulties facing you will be the naming of your specimen, but starting with the commonest ones and with a little practice, this becomes easier as your knowledge of how to look them up increases. There are many books written especially to help with this identification of different groups of animals and plants. There are also books which will tell you how to collect and preserve your specimens. The list below contains books of both kinds which you will find useful.

Author	*Title*	*Publisher*
Adams, C.V.A. (1959)	*Nature is my hobby.* (This tells you how to make collections of different kinds of animals and plants.)	Wheaton
Knight, M. (1960)	*The young field naturalist's guide.*	Bell
Newman, L. Hugh (1958)	*Instructions to young naturalists: II Insects.*	Museum Press
'The Observer Books'		Warne

The series includes the following titles:

Clegg, J. (1956)	*Pond Life.*
Jewell, A. (1955)	*Mosses and liverworts.*
Rose, F. (1963)	*Ferns.*
Rose, F. (1963)	*Grasses, sedges and rushes.*
Stokoe, W. J. (1937)	*Butterflies.*
Stokoe, W. J. (1956)	*Wild flowers.*
Stokoe, W. J. (1960)	*Trees*, 2nd revised edn.
Wakefield, E. M. (1954)	*Common fungi*

Chapter 2

Investigating living things

2.1 Becoming scientific detectives

Most of us are interested in the things we see and find out-of-doors and would like to know more about them for our own enjoyment. Many of us would like to feel that we could contribute something to what is known about an animal or plant in which we have been interested, or about living things in one of our favourite places. But we might think that there is nothing we could say that had not been said already, nothing we could observe and record that had not been observed, recorded, and written about a thousand times before.

But we would be quite wrong. For as we learn how to look at things and how to use books we begin to realize that there are a great many gaps in man's knowledge. Did you realize, for instance, that we know practically nothing about the life of a whale? You might say that whales, because they live in the sea and often very deep down, are difficult animals to observe, and you would be right, but it would be equally true to say that we know very little about some of the commonest animals which are easy to observe but which have, so far, escaped the more careful attention they may well deserve. Some starlings leave us to fly to warmer countries in autumn, while others at the same time arrive in this country to spend the winter with us. Still others stay here all the year round. What is the reason? Is it always the same starlings that migrate or stay at home? Biologists have not yet answered these questions.

In the next few weeks *you* are going to become scientific detectives, finding clues, following them up and working out your own plans for solving problems. Some will never be solved, but then, like many things, it is not necessarily the solving of a problem, but the enjoyment gained from following up the clues, that makes it worth while.

What are the qualities of a good detective? First, and most important of all, he must be someone who can use his eyes, not just for watching the main character in the crime, but all the other things around that may help to build up a full story. Second, having made his observations, the good detective writes them all down in a notebook. Later he will go through his notes and from these he will

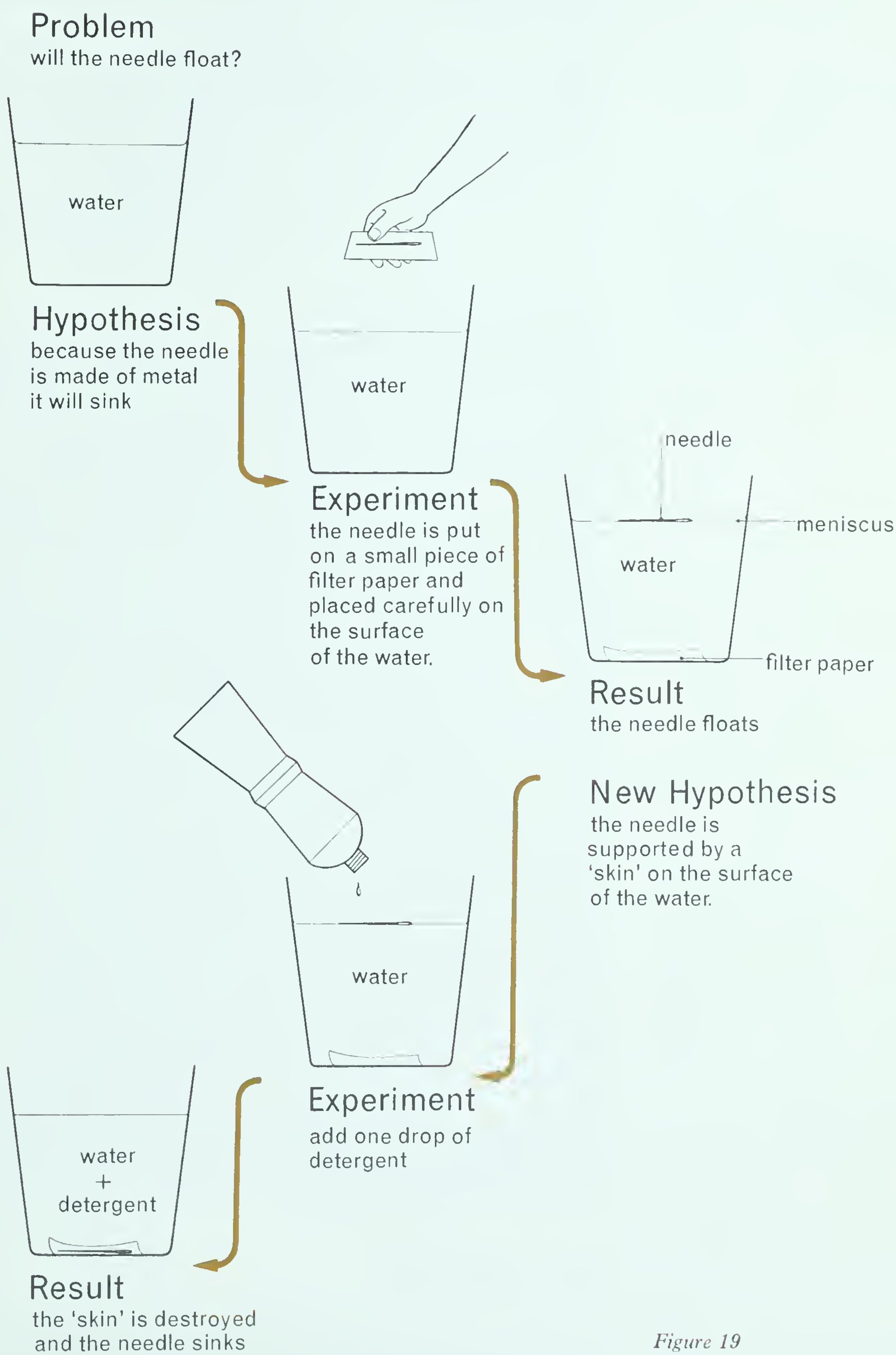


Figure 19
The stages in making a scientific enquiry

make a full record of his case. From this record he may have a bright idea of how he thinks the crime was committed. Such a bright idea in biology is often called a HYPOTHESIS. It is a long word but really means an idea which must be tested. If it is found to be no good, then it must be discarded and a fresh hypothesis made in its place.

Being a scientific detective means that you must be able to *observe* and *record* your observations accurately, make your own *hypothesis* from your records and invent *experiments* to test your hypothesis.

We could represent the stages of enquiry thus:

PROBLEM → HYPOTHESIS → EXPERIMENT → RESULT

Let us take an example.

You may have heard of the old saying that a sewing needle will float on the surface of water in a tumbler. Can a needle really float? Here is the *problem*, then. You might make a *hypothesis* that because the needle is made of metal it will sink. You can then go on to test your hypothesis, making an *experiment* by putting a sewing needle on a piece of filter-paper and floating this carefully on the surface of a tumbler of water. What happens? The needle floats, while the filter paper sinks. Your hypothesis has been proved to be wrong and you must think out another one. For instance you could say that a sewing needle will not sink because there is a 'skin' on the surface of the water. Again you must test this hypothesis by an experiment. This time you will have to invent some way of destroying the 'skin' to support your hypothesis. Another sewing needle is floated on the water in the same way as before, but this time one drop of liquid detergent soap solution (such as you use for washing up) is added and the surface 'skin' is destroyed. The needle sinks. Thus you have proved your hypothesis. Figure 19 shows the stages of this enquiry in the form of a series of pictures.

In the work you will be doing you will be making scientific enquiries like this one. Some of these enquiries will involve watching animals and plants and may go on for several weeks. So that just as a detective may have to wait a long time for results, you may sometimes have to wait too, and during that time you will be keeping a record of the progress of the experiment.

Many of the things you will discover will be things that are already known, but remember what we said at the beginning. There are still many quite ordinary things we know nothing about, and this is where your powers of detection will come in because you may find out something quite new.

2.2 Earthworms

You can start your investigations in an ordinary garden, looking for quite common animals – earthworms, for instance. Have you ever wondered what makes the small piles of leaves collected in

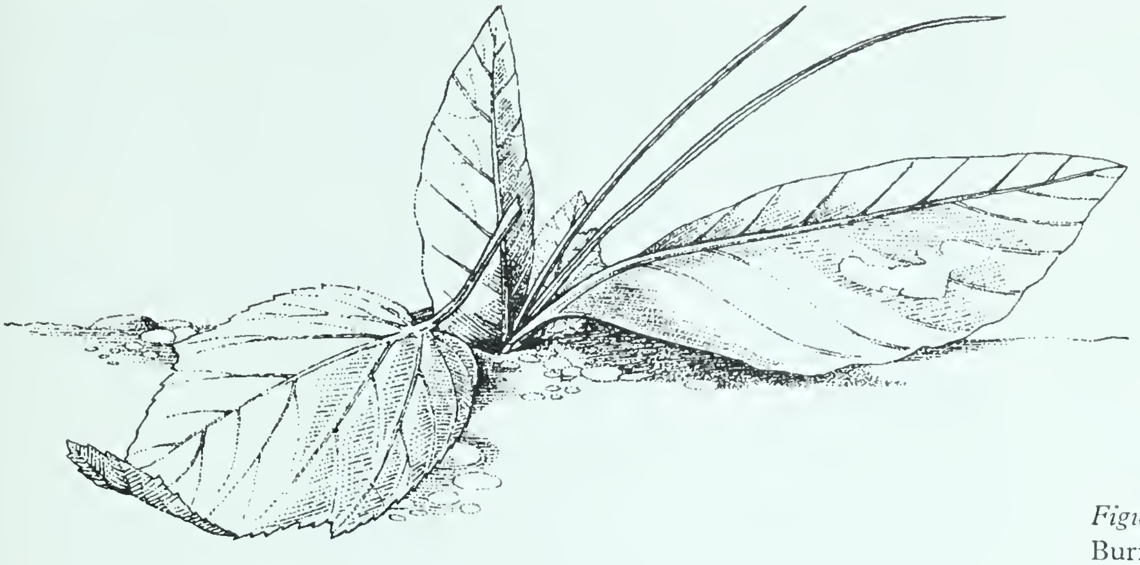


Figure 20
Burrow plug of a common earthworm (*Lumbricus terrestris*). Leaves and other material are drawn into the burrow entrance.

different parts of a lawn, or the small mounds of gravel all over a gravel path? If you go out after dark and shine a torch on a patch of lawn, you may be quick enough to see an earthworm retreating into its burrow beneath one of the piles of leaves like the one in figure 20.

For a long time earthworms have attracted the attention of gardeners and others interested in the cultivation of crops. Nearly 200 years ago, the Rev Gilbert White, author of the famous book *The Natural History of Selborne*, said that 'the earth without worms would soon become cold, hard-bound, and void of fermentation, and consequently sterile'. Later, in 1881, another famous biologist, Charles Darwin, published an important book called *The Formation of Vegetable Mould Through the Action of Worms.* This is a long title but one which will mean much more to us when we have finished our investigations.

In his book Darwin said: '*It may be doubted whether there are any other animals which have played such an important part in the history of the world as these lowly organized creatures.*' This is a bold statement to make about mere earthworms and yet the more we learn about them, the more we realize what interesting habits they have and how much man owes to their activities. Strange to say, biologists knew practically nothing about the life history of the earthworm until about 1945, and there still remains a great deal to find out. Your observations, then, might even reveal something new.

The common earthworm (*Lumbricus terrestris*) is one of our largest earthworms. When it is fully grown it may be as long as ten inches, and very like the long worm (*Allolobophora longa*) in both appearance and size. In fact these two kinds of worm are the largest of all the earthworms in this country. (There are about thirty-seven different British species.)

2.21 Using a hand lens

Earthworms are quite small animals and if we are going to find out more about them, we must be able to see how their bodies are made. In order to see small structures and make out things which we cannot see with the naked eye, we must try to make them look larger than they really are. To do this we use a lens. The kind of hand lens usually used in a biology laboratory magnifies an object either five or eight times.

Since you will often be using hand lenses, it is important that you should learn how to use one properly. There is a right and a wrong way of doing this.

You can practise by looking at the skin on the back of your hand. Figure 21 shows how to do it.

1. Hold the lens about three inches from one eye keeping the other one open if you can.
2. Now, holding your other hand palm side down, bring it up to the lens until it is about six inches away.
3. Continue to move it slowly and, as you do so, the skin on the back of your hand will gradually become clear (be *in focus*).

You will notice that not only is your skin much magnified but you will be able to see things on the surface of the skin, such as hairs and wrinkles, which you could not see before.

Figure 21
The right way to use a hand lens. Note that the object is brought towards the lens and not the other way round.

2.22 Looking at the structure of the common earthworm (*Lumbricus terrestris*)

Now you are ready to look at an earthworm more closely and find out about its structure.

1. Hold a worm near the pointed end, which is its head, between the finger and thumb, and focus it under your lens. You will find that the worm wriggles but in spite of this you should be able to make out some of the structure.
2. Notice that the body of the worm is made up of a number of rings or segments, and that those at the front, or anterior, end of the body can be extended greatly. This is the action that the worm uses in pushing through the soil.
3. With the lens still focused on the head of the worm, make out the first segment, called the *prostomium*, and the second segment, called the *peristomium*. Look for the mouth between these two segments on the underside of the head. Figure 22*a* shows a side (lateral) view of the anterior end of an earthworm and figure 22*b* shows the anterior end from underneath (ventral view).
4. Put the lens down and pass your fingers along the worm from the head towards the tail and feel its slimy skin. Now pass your

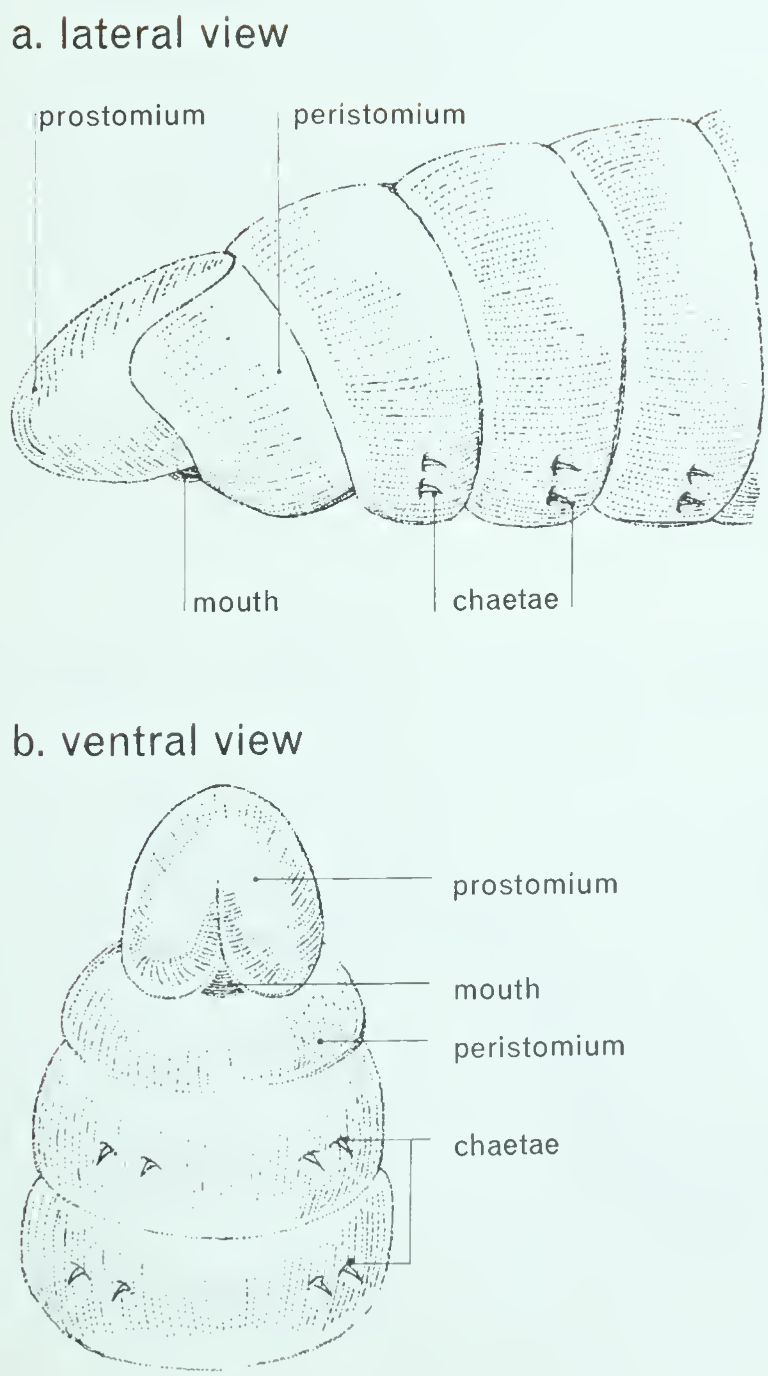


Figure 22
Enlarged view of the anterior end of the common earthworm (*Lumbricus terrestris*).
a. Lateral View.
b. Ventral View.

Note the position of the mouth and the *chaetae* arranged in pairs along the sides and underneath the worm.

fingers back again towards the head end. Can you feel some tiny bristles? Figures 22*a* and 22*b* show these bristles (*chaetae*). There are four pairs on every segment except the first two and the last. Later we shall see how important the *chaetae* are to the worm.

2.23 Finding out about how an earthworm moves

We have already discovered that the pointed end of the worm is its head. By allowing it to crawl on a sheet of brown paper we can learn more about the worm and how it moves.

1. Put a large earthworm on a sheet of brown paper and, looking at figure 23, notice the pointed head end of the worm and the flattened tail end. Find the saddle (*clitellum*) nearer the head end and the red blood vessel which shows through the skin and runs all along the back.
2. Watch how the worm moves forward by extending the anterior end of its body. To do this the rings also extend and this part of the worm becomes much longer and thinner. At the same time the rest of the body becomes fatter and shorter. In fact, if we watch carefully, we can see that all the rings right down the body are extended in turn, while other rings contract. Figure 24 shows a series of pictures of worm movement with alternate expansions and contractions of the body as the worm moves forward.
3. Listen carefully as the worm moves over the paper. Can you hear a faint scratching noise?
4. How does the anterior end of the worm grip whilst the rest of the body is drawn up? Put the worm on a glazed tile. How does it move now? How is this kind of movement different from that on the paper?

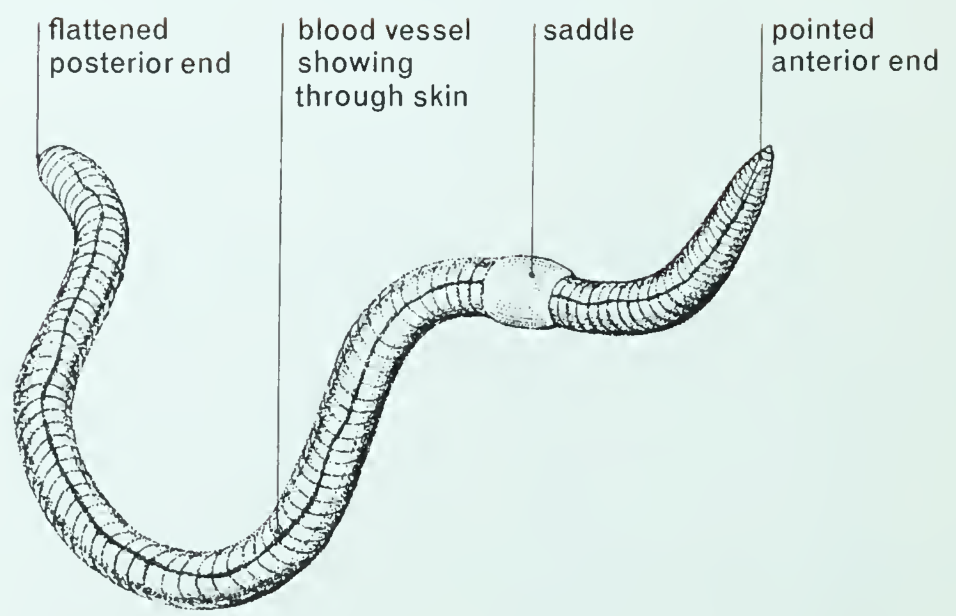


Figure 23
The common earthworm (*Lumbricus terrestris*) × $\frac{2}{3}$.

If you go out after dark, as we suggested in section 2.2, and shine a torch on a lawn, you will be surprised at what you see. There will probably be a great many worms all over the lawn with the front part of their bodies extended right out of their burrows. The bright light from the torch will send the worms shooting below ground, but if you are quick enough, you may be able to catch hold of a worm before it retreats into its burrow. Worm hunting is good sport and you will be surprised how firmly they can hold onto the soil underground with the tail end. This is because the *chaetae* on each ring of the body grip the sides of the burrow and it explains why worms always leave some of the hind parts of their bodies in the burrow. Birds, too, find difficulty in pulling a worm out of its burrow. If you have not realized this, watch a blackbird feeding on a lawn after rain.

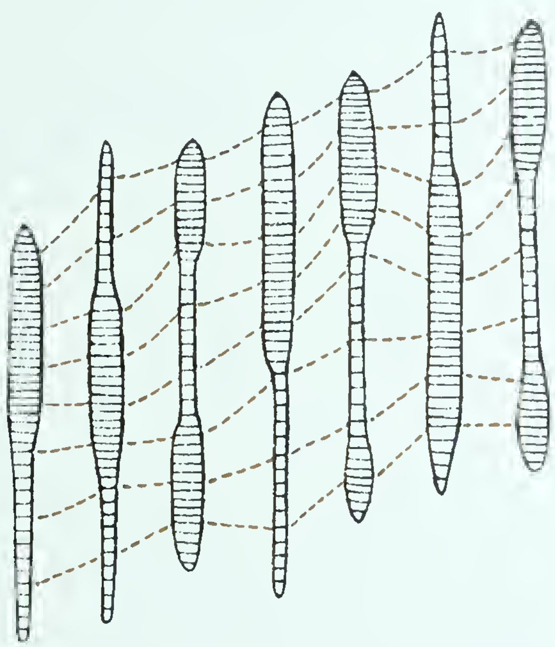


Figure 24
Diagram to show how an earthworm moves.

Can you tell which way the worm is moving?

2.3 How earthworms help to enrich the soil

The biologist, Charles Darwin (section 2.2), found out a great deal about the habits of earthworms and, in particular, about the way in which they make the soil richer by pulling leaves and other scraps of vegetable matter down into the soil. He also found that earthworms bring soil up to the surface in the form of casts when they burrow, by eating the soil and passing it through their bodies. He calculated that they could bring up to the surface of the ground as much as twenty-five tons of soil to an acre each year. If this soil were spread out, it would cover an acre to a depth of nearly a quarter of an inch. Since earthworms cannot swallow particles larger than 2 mm in diameter, this means that in ten years a field could become covered by fine soil to a depth of nearly $2\frac{1}{2}$ inches.

But Darwin did not realize that the common earthworm burrows and feeds in a different way from the long worm. It makes a U-shaped burrow by swallowing the soil as it burrows. This soil passes through the worm's body and most of it is cast beneath the surface and pressed onto the sides of the burrow. The long worm makes casts of soil on the surface. Thus, the calculations which Darwin made for the amounts of soil brought up to the surface, did not take into account the great quantity of fine soil which passes through the bodies of common earthworms and which remains below ground level.

On the other hand the long worm very rarely plugs the entrance to its burrow with leaves as the common earthworm does.

2.31 How earthworms feed and help to break up the soil

Probably, we shall not be able to watch a worm actually feeding, since this happens mostly at night. But we can see the effects of feeding by carefully examining part of a leaf drawn into a burrow. It is usually moist and the veins of the leaf may be all that remain of the portion below ground.

The worm grasps the edge of the leaf or sometimes a leaf stalk between its flexible prostomium and its mouth. By a sucking action it gradually draws the leaf into the entrance of its burrow. The worm

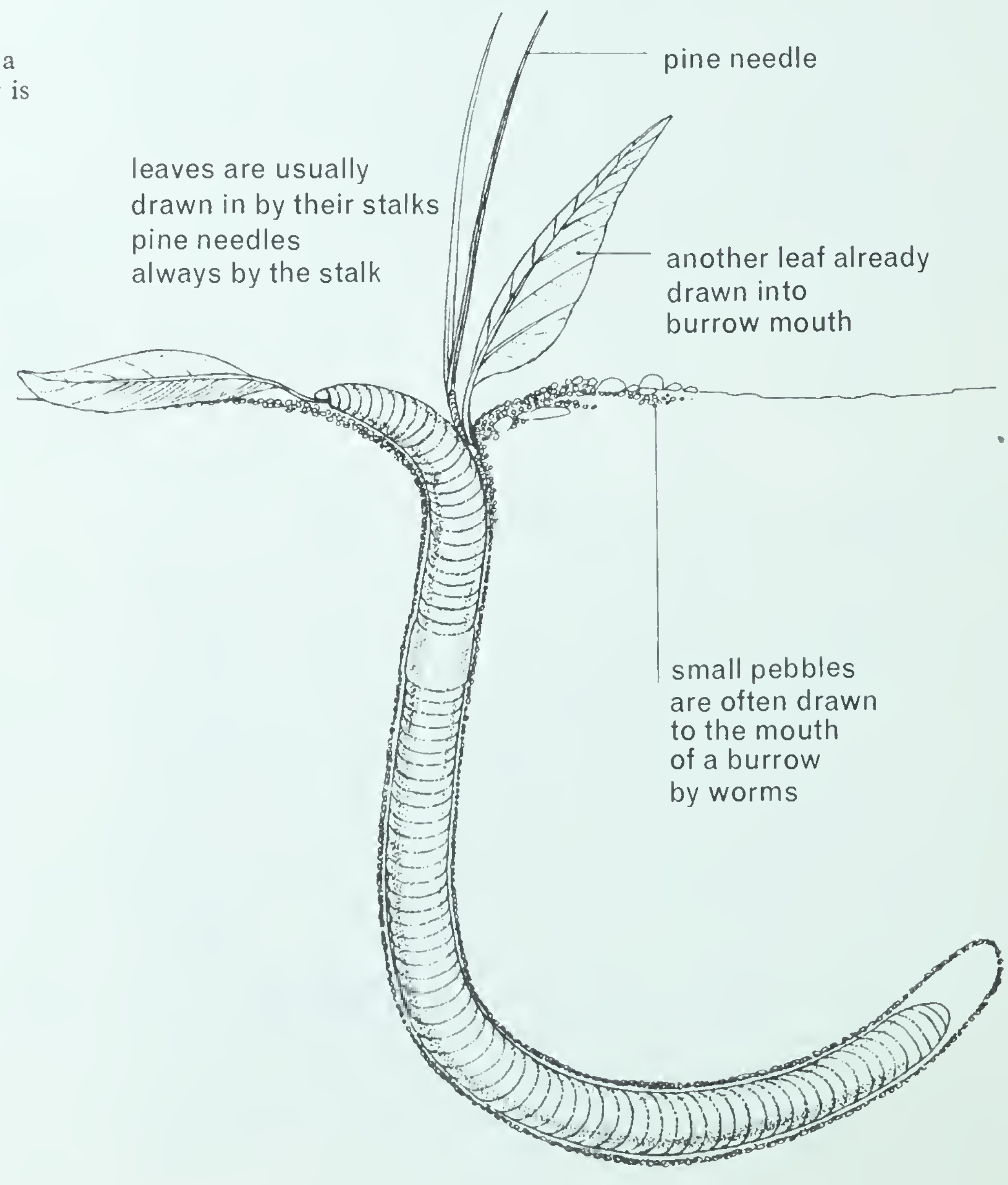


Figure 25
A common earthworm drawing a leaf into its burrow (the burrow is shown in section).

pours special digestive juices onto the leaf to soften it before it is eaten. Figure 25 shows a common earthworm with its head projecting and drawing a leaf into the entrance of the burrow. This would probably happen at night.

Worms will even drag small stones to the mouths of their burrows; you can often see small piles of stones in a hard gravel path that indicate the presence of a worm burrow.

Worms feed not only on leaves and other vegetable matter, but also by eating the soil itself. This is especially true when they are making their burrows. When we say they eat soil, what we really mean is that the worms swallow the grains of soil amongst which are particles of vegetable matter which is their real food. The soil grains pass through their bodies unchanged, apart from being ground into finer particles. They are then expelled at the tail end of the worm, below the surface of the ground, in the form of a cast. In this way earthworms help to break the soil down into fine particles. They can be said to help the gardener to dig.

2.4 Finding out about the habits of earthworms

We can do several experiments to find out more about the habits of earthworms. For instance you could find out what kinds of materials the common earthworm prefers for plugging its burrow by offering a choice of different things. First, you must look for burrows already plugged in different places. Then, by offering the same selection of materials in each kind of place, you may be able to find out if worms prefer one kind of leaf more than another. Do worms living in hard soil beneath a gravel path choose different things to plug their burrows from those living in soil beneath a lawn or soil in a garden which has not recently been dug? You may also be able to find out if they eat the leaves and other materials with which they plug their burrows.

1. Find about five worm burrows with plugs, in each of the following areas, and place a 4 inch plant pot over each burrow to mark the spot.
a. A hard gravel path.
b. Soil on a garden border not recently dug.
c. A grass lawn.
2. Number each plant pot with chalk.
3. Lift each pot and carefully remove all vegetable matter (leaves, sticks, etc.) from the worm burrow and place a selection of vegetable matter (it must be the same in each case) under every pot. Do not pile the leaves up but spread them out as much as possible. Here are some suggestions for materials you could use:
1 pine needle
1 dead leaf of lime, apple, or rose
1 dead leaf of oak or beech
1 small leaf stalk or twig
1 small strip of mint
1 green leaflet of ash, elm, or elder

4. Leave the experiment for one week, then go round lifting the plant pots in turn and look carefully to see what has happened. What material has been pulled down into the burrows? Record your results, for each burrow, against the number of each pot. Replace the pots as you go. At the end of the week your record should look like the one below but with your own ticks in the correct places.

5. Make a note of whether it has been rainy, damp, dry, or frosty weather.

Weather Record:

No. of pot	*Situation*	*Pine needle*	*Lime leaf*	*Oak leaf*	*Twig*	*Mint leaf*	*Ash leaflet*
1	Hard path	√			√	√	√
2	Hard path						
3	Hard path						
4	Hard path						
5	Hard path						
6	Garden soil						
7	Garden soil						
8	Garden soil						
9	Garden soil						
10	Garden soil						
11	Lawn						
12	Lawn						
13	Lawn						
14	Lawn						
15	Lawn						

Examination of results

Looking at your results, can you answer the following questions?

a. Which kind of vegetable matter was selected by most of the worms for burrow plugging?

b. How many burrows were plugged by more than one kind of material?

c. Which kind of vegetable matter, if any, was not selected by any of the worms?

d. Some books say that worms dislike mint. Do you find this to be so?

e. If the pine needle was used for plugging any of the burrows, did you notice how it was drawn in? Was it drawn in by the tip of one of the double leaves or by the thicker base? Can you explain what you found?

f. On the whole, would you say from your results, that the worms preferred decaying leaves for plugging their burrows rather than fresh green ones? Can you give any reasons for this?

g. For what purpose does a worm plug its burrow? Think out as many reasons as you can.

h. Were the worms more active on warm, damp nights than on cold, dry ones? If so, can you give any explanation for this?

i. Did you find any evidence that a worm had actually chewed any of the vegetable matter plugging a burrow?

2.41 Setting up a wormery

There is a limit to the amount we can find out about living things by studying them in their natural conditions. For instance, we cannot find out much about how a worm burrows by looking at it on a lawn. So we must set up an experiment indoors and try to copy as closely as possible the conditions that exist outside. A wormery like the one in figure 26 is an attempt to produce the conditions that a worm finds underground. Since the glass sides are only an inch apart, burrowing activities are easily visible from outside. We can keep worms in a wormery like this for several weeks in order to observe their habits of eating, burrowing, and plugging their burrows.

This is how you should set up the wormery:

1. Using a bottle with a sprinkler top, moisten the garden soil that you are going to use.

2. With a spoon, put a layer of this garden soil, about $1\frac{1}{2}$ inches deep, in the bottom. Then a very thin layer of sand, followed by another $1\frac{1}{2}$ inches of soil and a very thin layer of powdered chalk. Repeat these layers ending with a soil layer and leaving about $1\frac{1}{2}$ inches free at the top of the wormery. Each layer should be made fairly firm, and as level as possible, using a ruler, before the next layer is added.

3. On top, place a selection of things you think the worms might like to eat. Try various kinds of damp, decaying leaves, small cubes of apple, scraps of celery, onion, raw meat, and chocolate (apparently a favourite food!).

4. Now you are ready to put in the worms. Choose four large common earthworms and put them on top.

5. Now put on a cover made from a strip of perforated zinc, firmly held in place (or tie over a piece of Polythene sheet, pricked to allow

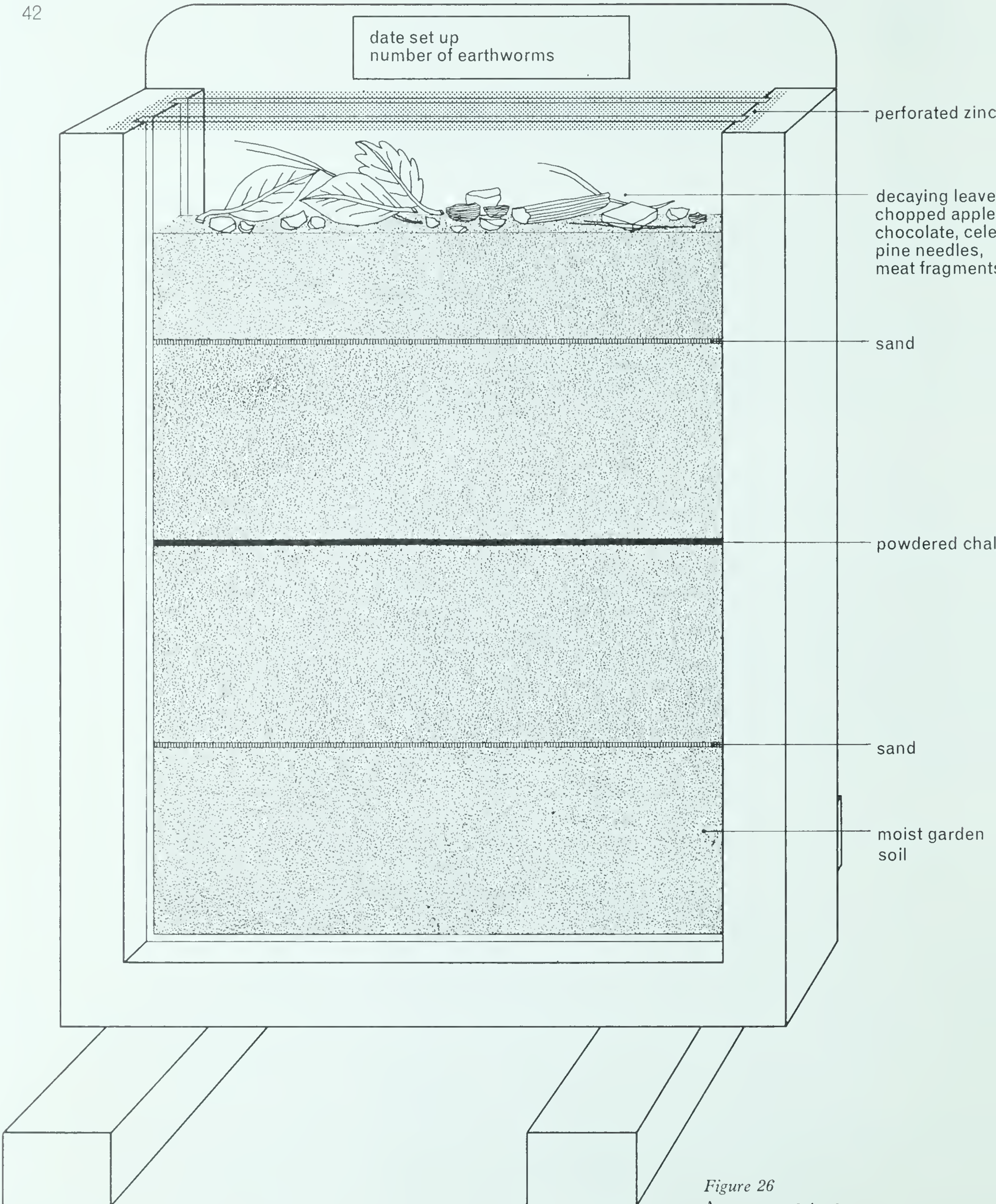


Figure 26
A wormery set up.

the air to enter) to prevent the worms escaping. At first they will probably wriggle about but after a little while they may start to burrow. Watch how they push their heads into the soil by extending the first few rings and then drawing up the rest of the body. This action is repeated until the burrow is made and they are under the surface. It may take some time.

6. Place a sheet of cardboard cut to size, over each glass side to keep out the light.

7. Lastly, write the date on a label attached to the wormery, and the number and kind of earthworms you have put in.

8. After a week take the cardboard covers off the glass sides of the wormery and try to find answers to these questions.

Food

a. What kinds of leaves and other vegetable matter have been dragged below the surface of the soil? Are there any which are left untouched?

b. Have the leaves been drawn in by their blades or by their leaf stalks?

c. Has the chocolate or raw meat been eaten?

Burrows

d. What shape are the burrows? To help you answer this, you could mark the direction of the burrows with chalk on the glass side of the wormery.

e. Have the burrows gone through the layers of chalk and sand; have they mixed these layers?

2.42 What do common earthworms choose as food and how do they find it?

In the wormery we offered a selection of materials on the top of the soil. But these may be used to plug burrows as well as for food. How can we find out if worms feed below ground besides eating food which they find on the surface and drag to their burrows?

We can invent an experiment to discover whether earthworms like some foods more than others, and how they find their food. To find the answers to these two questions; we must keep worms in another kind of wormery where they have more soil and greater room to move about.

1. Take two large plant pots, 1 and 2, about 8 inch diameter, and place a piece of broken plant pot in the bottom, over the hole.

2. Fill Pot 1 with good garden soil to within 2 inches of the top, pressing it down as you go. Dampen the soil *before* you put it into the plant pot.

3. On top of the soil and spaced out over the surface place three small bits, about $\frac{1}{2}$ inch square, of red cabbage leaf, three of green

cabbage leaf, three ½ inch cubes of onion, and three of turnip.
4. Cover with ¼ inch of garden soil and press it down. Figure 27*a* shows Pot 1 in section.
5. Make up Pot 2 in the same way and with the same selection of food, but over each piece lay a small square of tinfoil (about 1 inch side), and then add the ¼ inch of topsoil. Figure 27*b* is a section through Pot 2 to show how to set it up.
6. Put four large common earthworms in each pot.
7. Cover each pot with a sheet of Polythene, tied over the rim of the pot and prick it to let the air in.
8. Label your Pots 1 and 2 and add the date. Leave until next week.

Recording results
1. After a week take the Polythene sheets off Pots 1 and 2 and carefully scrape away the top ¼ inch of soil with a spoon.
2. In Pot 1 the food fragments were not covered with squares of tinfoil. Examine each fragment carefully and, using a table for your results like the one below, put a tick against any food which shows signs of being eaten. Two ticks against 'green cabbage leaf' means that two fragments of green cabbage out of the three offered show signs of being eaten. Whereas no ticks against the 'red cabbage leaf' means that none of the fragments of the red cabbage was eaten.

POT 1

Date set up	Results recorded on ......
Red cabbage leaf	
Green cabbage leaf	
Onion	
Turnip	

3. In Pot 2 each portion of food was covered by a small square of tinfoil. Lift off the tinfoil squares and examine each piece of food for signs of eating. Record your results in the form of a table as you did for Pot 1.
4. Remove each piece of food and look to see if there is a burrow underneath.

Can you answer the following questions:
a. In Pot 1, of the various kinds of food offered, which seems to be the favourite?
b. If one kind of cabbage leaf was preferred to the other, can you suggest any reasons?
c. In Pot 2, if none of the fragments of food, or only a few, showed signs of chewing, can you give a reason?
d. Were there any signs of worm burrows beneath any food fragments in Pot 2? If not, can you suggest how the worms reached the food?
e. Why were you asked to put squares of tinfoil over the food in Pot 2?

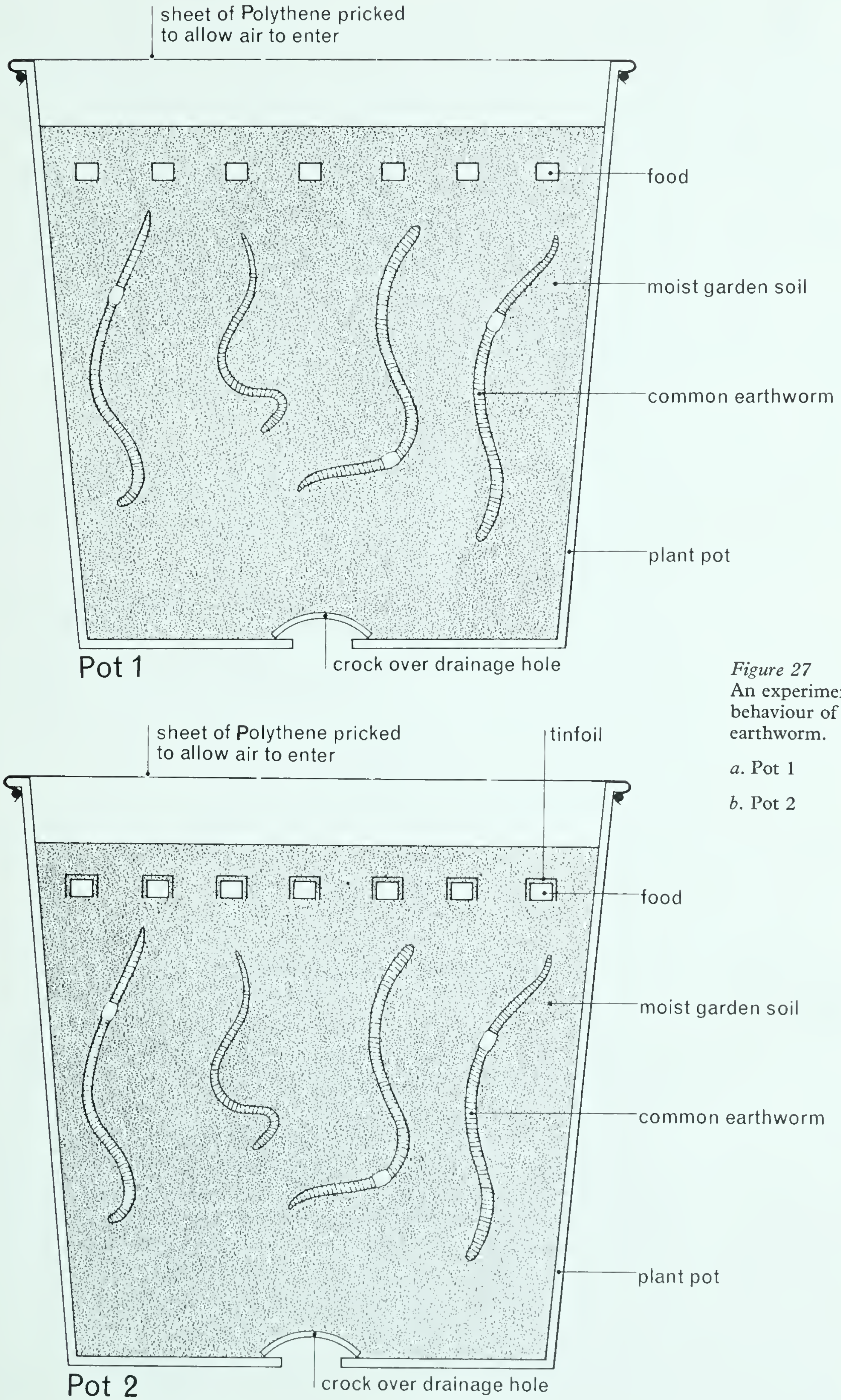


Figure 27
An experiment to study the feeding behaviour of the common earthworm.

a. Pot 1

b. Pot 2

f. On the whole, would you say that worms preferred strong-smelling food to the rest?
g. Can you suggest any other ways in which you could find out (1) what food worms prefer, and (2) how they find their food?
h. Would it be true to say that worms have a sense of smell? Have you proved this by these experiments?
i. The experiments in sections 2.41 and 2.42 were carried out in the laboratory to find out about the habits of earthworms. But the experiment in section 2.4 which was to find out what materials were chosen by worms to plug their burrows, was done out-of-doors with worms already living in the soil. Make notes of any ways in which this experiment helps to interpret the results you have obtained in the other experiments and vice-versa.

2.5 Earthworms as living things

It is easy to give examples of objects which are not living such as rocks and metal, and of man-made objects like tables, chairs, and pencils. But how can we be sure that an animal like an earthworm is living? What have we learnt about earthworms already that makes us quite sure about this?

A rock or a pencil cannot move, thus the fact that earthworms are able to move, immediately distinguishes them from non-living things. They move because they have received a message, or what biologists call a *stimulus*, to tell them to move. This stimulus, as we have seen, may be of several kinds such as light, cold or warmth, dryness or dampness, or vibration.

We have found that by shining a torch on a worm at night, it will immediately react and withdraw into its burrow. It does this even though it has no eyes with which to see the light. Here is a puzzle which we can only explain by saying that the worm appears to be aware of any light shining on its head end.

Thrushes and blackbirds have learnt that by stabbing the ground with their beaks, they can often make worms come to the surface. In the same way, if we push a garden fork suddenly into soil and work the fork about in the ground, worms will sometimes come up to the surface. Thus they must be able to feel vibrations in the ground. They certainly can feel the difference between warm and cold soil, as well as damp and dry, and they react to these differences as your experiments will have shown.

We may have been able also to show that earthworms can select one kind of food in preference to another. Is it possible, therefore, that they have a sense of smell and taste? The possession of senses which enable animals to react to different stimuli is another sure sign of a living thing.

2.6 Making and testing a hypothesis

You remember that at the beginning of this chapter we talked about becoming scientific detectives? In the experiment you did

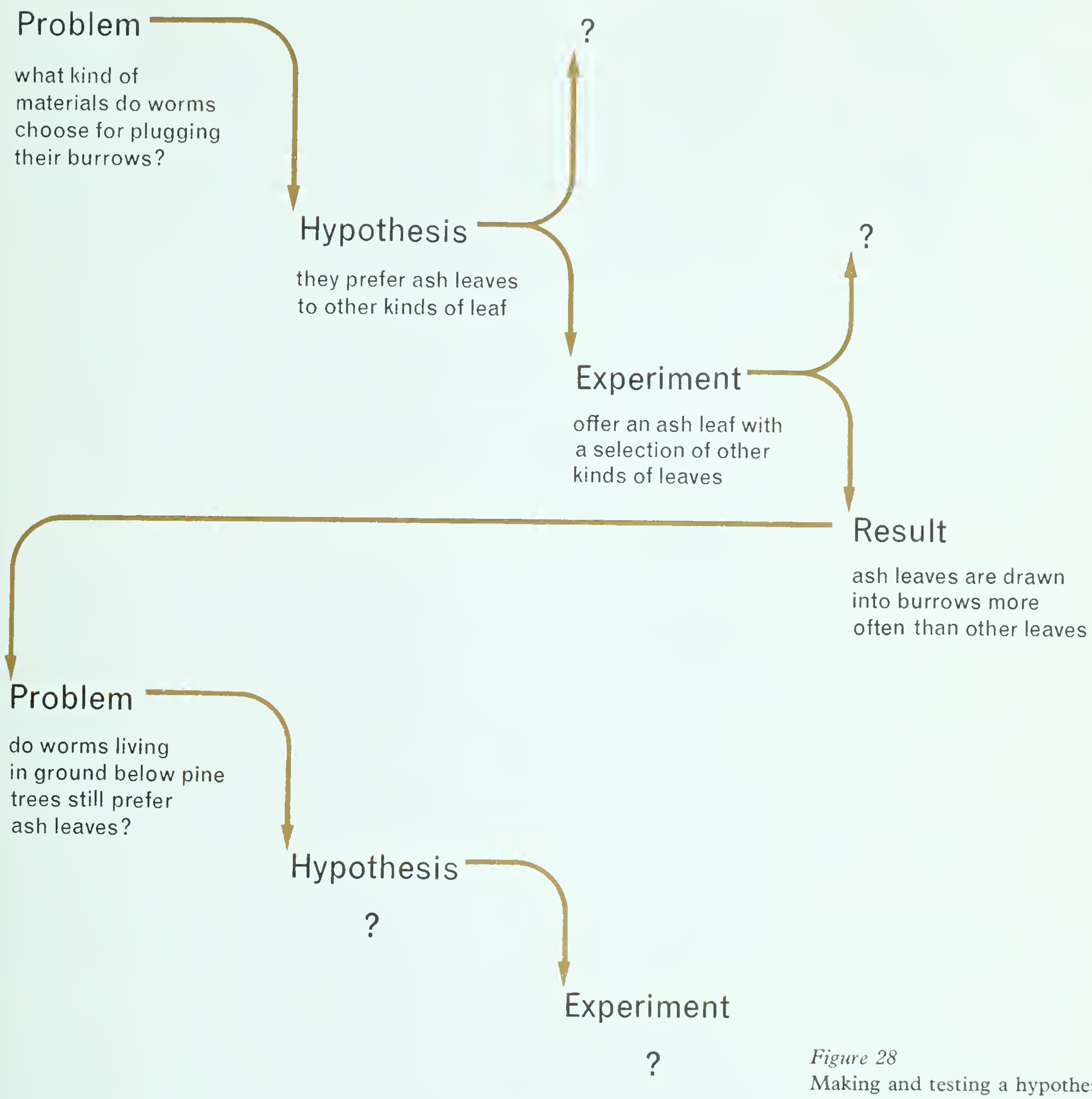


Figure 28
Making and testing a hypothesis on what common earthworms choose for plugging their burrows.

to find out what materials earthworms chose to plug their burrows (section 2.4) you really became scientific detectives for the first time.

The *problem* you were trying to solve was: 'What things do earthworms choose to plug their burrows?' You may have decided to make the *hypothesis* that they prefer ash leaves to other leaves and perhaps you designed an *experiment* to prove this. The *result* you got may have proved that you were right. But if this had not been so you would have had to invent another experiment or make another hypothesis.

The worms in your experiment may have preferred ash leaves but if you had put plant pots over several worm burrows under a pine tree and offered the worms only ash leaves, would they still have taken them into their burrows rather than the pine needles to which they were accustomed? Here we have another problem which means that you would have to make another hypothesis and design another experiment to test it.

This is what we mean by being scientific detectives – trying to solve a problem in a scientific way. In this course we shall be attempting to solve many more problems and in doing so we must remember the stages of a scientific enquiry which we have followed when investigating the behaviour of earthworms.

PROBLEM → HYPOTHESIS ↗→ EXPERIMENT ↗→ RESULT

Read this section through again, then look at figure 28 and see if you can now understand it better than before.

Summary

We have been investigating one kind of animal – the earthworm – and finding out about its structure, and how it moves. We have tried experiments out-of-doors to discover how worms burrow, feed, and plug their burrows. By burying leaves and other vegetable matter in the soil, thus enriching it for plants, they help gardeners and farmers to grow better crops. They also bring up vast quantities of good soil to the surface, in the course of their burrowing. In short, we would probably now agree with Charles Darwin when he said that earthworms have played a most important part in the history of the world.

By keeping earthworms in wormeries indoors, we have discovered how they can mix up the layers of the soil. By offering them a selection of food we have found out something about their likes and dislikes and how they find their food.

Some of the investigations carried out so far have been done outside; but there is a limit to the amount you can discover about animals and plants in their natural state. When this limit has been reached, an experiment must be set up indoors such as our wormery. Much of the study of living things is carried out in this way – partly indoors and partly outdoors. As scientists, we must always be ready to switch at short notice from one method to the other and back again.

Background reading

Darwin, earthworms, and agriculture

On a cold December day in 1831, His Majesty's ship *Beagle* sailed from Plymouth on a voyage around the world which was to last five years. On board was a young naturalist, Charles Darwin, then only 22 years old.

Darwin, whose portrait as an older man you see in figure 29, was a born collector. In those days it was fashionable to collect things and many of our most famous museum collections were made then. But there was a difference in the purpose of the collections which Darwin made on his long voyage. To him the animals, plants, and fossils meant more than mere specimens in a museum. After he returned from the voyage he was to spend many years in studying and writing about the things which he had found. He wrote many books which were to make him, even during his lifetime, one of the most famous scientists that has ever lived.

The books were the result of many years of patient study often of quite ordinary animals and plants such as barnacles, orchids, and even earthworms.

No one would imagine that such a small and comparatively simple animal as an earthworm was of any importance. Yet Darwin spent many years in collecting information about worms, and finally in writing the famous book called *The Formation of Vegetable Mould Through the Action of Worms* mentioned earlier in this chapter. The book which may seem to us to have rather a dull title, was destined to become a best-seller.

Although Darwin had the advantage of living in a comfortable country house in Kent with a large garden in which he could work undisturbed, most of his observations and records about earthworms could have been made by anyone with the patience, time, and interest to do so.

How did Darwin set about his work and what is there that we can learn from his methods ? First of all we find that quite small things caught his attention. He noticed that if fallen leaves in a wood were swept away, the whole surface of the ground was strewn with worm casts and that the fine earth of the casts (the result of the worms actually eating the soil and passing it through their bodies) eventually buried the leaves falling once more on top of them. This layer of fine soil and leaves Darwin called vegetable mould.

In his book Darwin tells of a narrow path running across the lawn in his garden which was paved with flat stones. For several years the path was weeded and swept, but the worms threw up many casts and more weeds grew. In the end the gardener gave up weeding the path and thirty years later a layer of turf over three inches thick had formed on top of the paving stones.

In the same way Darwin noticed that stones in fields became buried in the course of a few years, by a layer of soil brought up to the surface by worms. Although he kept careful measurements of the depth of vegetable mould overlying the stones and checked and re-checked his observations, he wanted to find out more about the way in which the worms worked. So he kept some worms in large jars of soil in his study so that he could watch more carefully the way they made their burrows, plugged their entrances and made their soil casts.

From his various records Darwin found out that the layer of vegetable mould deposited on the surface of the ground by worms could be as much as an inch thick in a matter of a few years. As a

Figure 29
Charles Darwin (1809–82) at the age of forty: from a drawing by T. F. Maguire. *Radio Times Hulton Picture Library.*

means of checking his results, he resolved to collect, for a certain number of days, all the worm casts within a square yard of ground. He dried the soil of the casts and then weighed it. In this way he arrived, by careful experiment, at the astonishing conclusions you have read about in this chapter – namely that in the course of ten years worms could cover a field with soil to a depth of nearly two and a half inches.

It is easy to understand, therefore, how even quite large stones can become covered with soil cast up by worms. In the same way worms can be responsible, in the course of hundreds of years, for completely burying ancient buildings. In fact Darwin showed that earthworms play a most valuable part in preserving such buildings and even the beautiful mosaic pavements, cooking pots, and coins left by the Romans nearly two thousand years ago. By covering them with soil the worms have preserved the valuable historical remains from the action of frost and rain.

Many gardeners nowadays make use of earthworms to help them cultivate the ground so that they do not have to dig it themselves. By covering the soil with a layer of decaying leaves and other vegetable matter, the gardener can leave the rest to the worms. They will gradually draw all the vegetable matter down into the ground and at the same time their worm casts will cover the mould forming rich soil in which plants can grow. Thus the worms will do all the hard work!

Another way in which worms help the gardener and the farmer is by breaking up the soil into smaller particles. Have you ever noticed how fine the soil of a worm cast is? Try rubbing a cast between your fingers. The burrows which worms make are also useful in that they help the roots of plants to grow by allowing air and rain water to enter the soil. The fine soil produced in their casts on the surface helps to cover up the seeds of plants and provides them, too, with the conditions they need for growth. To quote the words of Darwin himself, 'The plough is one of the most ancient and most valuable of man's inventions; but long before he existed the land was in fact regularly ploughed, and still continues to be thus ploughed by earthworms.'

Chapter 3

Naming living things

3.1 Living things can be named by using a key

In the first chapter we discovered that there were so many living things on the earth, and so many more which have become extinct, that it would be quite impossible to find out about all of them, let alone find out all their names. But it often happens that, when carrying out an investigation, we want to know the name of a particular animal or plant. We may want to make a list of all the animals and plants that we could find in a garden, or we may want to distinguish between one animal and another one which looks very like it. When studying earthworms we may have come across a number of different kinds, each having two Latin names like the common earthworm, *Lumbricus terrestris* (*Lumbricus* = its genus and *terrestris* = its species). It is fairly easy to distinguish between two members of the cat family – a lion and a tiger for instance. But if we had to decide whether an earthworm was the common earthworm or the long worm (*Allolobophora longa*) we would have to make a very careful examination in order to find out which one it was. In other words, to distinguish between animals or between plants which look alike, we may have to look at their characteristics much more closely.

To find out the name of a plant or animal we could use a book with good illustrations and just turn through the pages of pictures until we came to one which seemed to be right. This is often a good way of identifying something, provided the pictures are detailed and accurate, and provided you make a careful comparison between the specimen and the picture. But, even so, there are often cases where the picture will not give you the answer, because it may not show the important features clearly. In any case, it would be expensive to buy enough books with good illustrations to name all the specimens you might find.

Because of these difficulties, most books which enable us to find out the names of things make use of what are called 'keys'. Such a key consists of a series of questions which, when you have answered them, lead you to the name of the specimen. This sounds quite easy, and you will find that it is, once you have had some practice.

3.11 An imaginary key

Suppose you wanted to make a simple key to distinguish between the five animals belonging to the arthropods which are drawn in figure 7, Chapter 1. Look at figure 7 again. You might make up a series of clues arranged in pairs which are bracketed together like the one below:

1.	Has wings	DRAGONFLY
	Has no wings	2
2.	Has not more than eight legs	SPIDER
	Has more than eight legs ..	3
3.	Has not more than 10 legs ..	CRAB
	Has more than 10 legs ..	4
4.	Body flattish. One pair of legs to each body segment ..	CENTIPEDE
	Body round. Has two pairs of legs to each body segment ..	MILLIPEDE

Each pair of clues has a number in front of it. Suppose you wanted to use this key for identifying one of these animals. You could practise by starting with an animal that you know. Suppose that you want to identify a centipede. Start with the first pair of clues and decide which of them applies to a centipede. Has it got wings or no wings? Obviously it has no wings. At the end of the line 'Has no wings' is the number 2. This means that you should now look for the pair of statements with the bracket number 2. Again, there are two statements. Which applies? Has a centipede got eight legs or more than eight legs? The answer is more than eight legs, so you now go on to the pair of clues numbered 3. The centipede has more than ten legs, so you go on to the last pair of clues numbered 4. Which of these applies? Clearly the body of a centipede is flattish with one pair of legs to each body segment.

This particular key is really of no use because you knew the names of all the animals already, but it would have been useful to someone who did not. Keys to the names of animals and plants are not usually so simple and to use them correctly you may have to look at the characters of the specimens very carefully. If you go wrong, you will probably soon find out, because at some point the specimen you are trying to name will not fit either of the pairs of clues. So you will have to go back to the beginning again.

3.12 Using a key

The best way of getting practice in the use of a key is to start with a specimen you know well and work backwards.

Let us try this method by using, for example, a key for the identification of the twigs of five common trees you could find at this time of the year.

You will know at least one of the twigs very well – the horse-chestnut with its sticky buds.

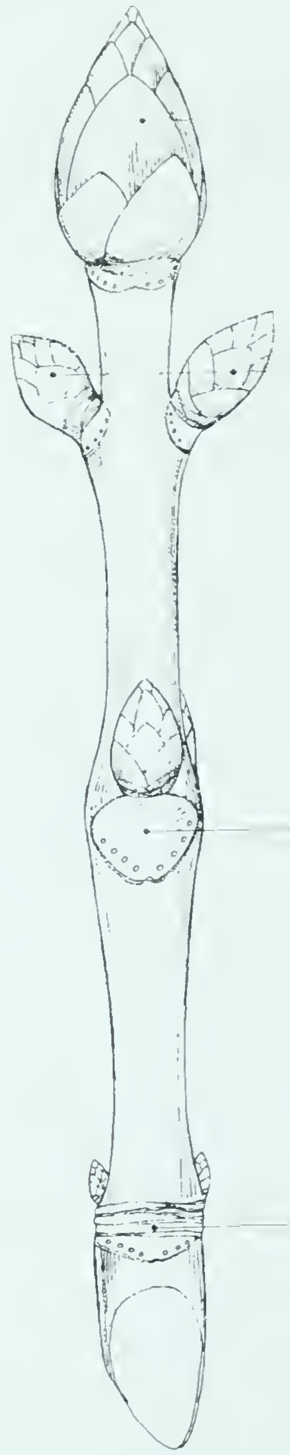


Figure 30
Winter twig of the horse-chestnut.

1. Look at the twig of horse-chestnut and at figure 30 and make notes in your notebook of some of its characteristics. Here are some questions to help you to make your notes:
Are the bud scales red-brown and sticky?
Is the leaf scar horseshoe shaped?
Are the buds arranged in pairs, opposite each other?
Are the buds less than four times as long as broad?
2. When you have noted the answers to these questions, look at the key below. You will find horse-chestnut against the number 3 in the lefthand margin. Now work backwards, using the answers you have noted to the questions above. Do they fit? If so, you have proved that the twig is horse-chestnut.
3. Now look at the other twigs in turn, using the key the right way

round, or starting with the first pair of characters. See if you can find the correct names to the other twigs.

Key to some common winter twigs

1.	Buds more than 4 times as long as broad ..	2
	Buds less than 4 times as long as broad ..	3
2.	Buds cigar-shaped – leaf scar nearly surrounds base of bud	BEECH
	Buds not cigar-shaped. Leaf scar much smaller	BIRCH
3.	Buds smooth, green-brown or black ..	4
	Bud scales red-brown, sticky. Leaf scar horse-shoe shaped	HORSE-CHESTNUT
4.	More than 2 green-brown bud scales ..	LILAC
	Only 2 black bud scales	ASH

3.13 What have we learnt from the key?

By now you will have realized that the key you have just used is built up by selecting pairs of characteristics which force you each time to select one and reject the other. This means that you have to examine each twig to decide which of the pair of characteristics is the right one, and if you go wrong it will be because you have not made a sufficiently careful check.

If you have used this key properly, you will have found out the correct names of these winter twigs. Now it should be easier for you to use other keys for the identification of such things as the leaves of trees or garden weeds or even pond animals.

3.14 Making a key

Using keys made by other people is quite interesting but not nearly such fun as making a key of one's own.

You can make a key to almost anything. What about making one for some of the different kinds of dogs you know?

Suppose you want to make a key to distinguish between six kinds of dog which you have identified beforehand. Let us say you have chosen the following breeds: fox terrier, golden labrador, golden retriever, black and tan dachshund, toy poodle, and chihuahua. The first thing you do, when you make any kind of key, is to write out a list of all the features you can think of which would help to distinguish one specimen from another.

1. Make your list of these features across the top of a page in your notebook and a list of the breeds of dog down the side of the page like this:

Breed of dog	*Size*	*Colour*	*Ears*	*Fur*
Fox terrier	Medium	Black and white	Short	Short
Golden labrador	?	?	?	?
Golden retriever	?	?	?	?
Black and tan dachshund	?	?	?	?
Toy poodle	?	?	?	?
Chihuahua	?	?	?	?

2. If you can think of any other important features, then make more columns along the top of your page to take these extra notes about each kind of dog.
3. Now make notes in the right columns for each breed of dog. The first set of notes for the fox terrier has been filled in to help you. When you have completed all the columns, you will be ready to make the key itself.
4. If you are in any doubt about how to proceed, have a look at the key you have already used for identifying the winter twigs of trees and try to model yours on that using your own list of features for the breeds of dogs.

You could make a key to different kinds of motor car in the same way.

3.15 Living things vary

Making a key to a group of plants and animals looks easy until you try it. What parts of key making have you found difficult? One problem which often causes trouble is how to select for comparison plants and animals which can be described as *typical* of the group to which they belong. In a previous investigation (section 3.13) you were looking at twigs which were as 'typical' as possible of those growing all over the tree, and no doubt you had a rough idea of what was meant. But often making a selection of this kind is more difficult.

Suppose you wanted to construct a key for the identification of each member of your own class. First you would choose the obvious differences – boy or girl, blue eyes or brown eyes, tall or short, dark hair or light. If there were thirty in the class you would find that these few characteristics were not sufficient to identify every individual member and they would be difficult to apply in every case. For instance, the colours of eyes range from clear blue through grey and light brown to dark brown with many other shades in between.

So we see that there is no such thing as a 'typical' human being any more than there is a 'typical' twig. Every human being is different – they vary one from another. In fact *variation* is a feature of all living things and the reason why we are justified in talking about plant structures as 'typical' is because, on the whole, they vary less than human beings. We are thus able to make keys to identify them in spite of their variation. However, we have warned you that sometimes variation, even between plants of the same species, may be greatly increased. Take, for instance, the leaves of one plant grown in the light and compare them with leaves from the same kind of plant grown in the shade. The differences between them are sometimes so great that it is hard to believe that they could both belong to the same species. Try growing two lots of mustard seeds, one in full light and the other in the dark. You will be surprised at the result.

We have now arrived at one of the simple rules for making a key. The differences between species that we choose must be greater than those which normally occur within a single species as a result of variation.

3.16 How much do we vary?

Earlier, we mentioned various features of ourselves that vary – colour of the eyes, height, colour of hair, and the like. In science we are constantly concerned with measuring things in order to find out about them more exactly, so suppose we make measurements in order to try to answer the question – *how much* do we vary? A convenient part to measure is the length of the middle finger since this can be done with a ruler and since you can easily measure it yourself.

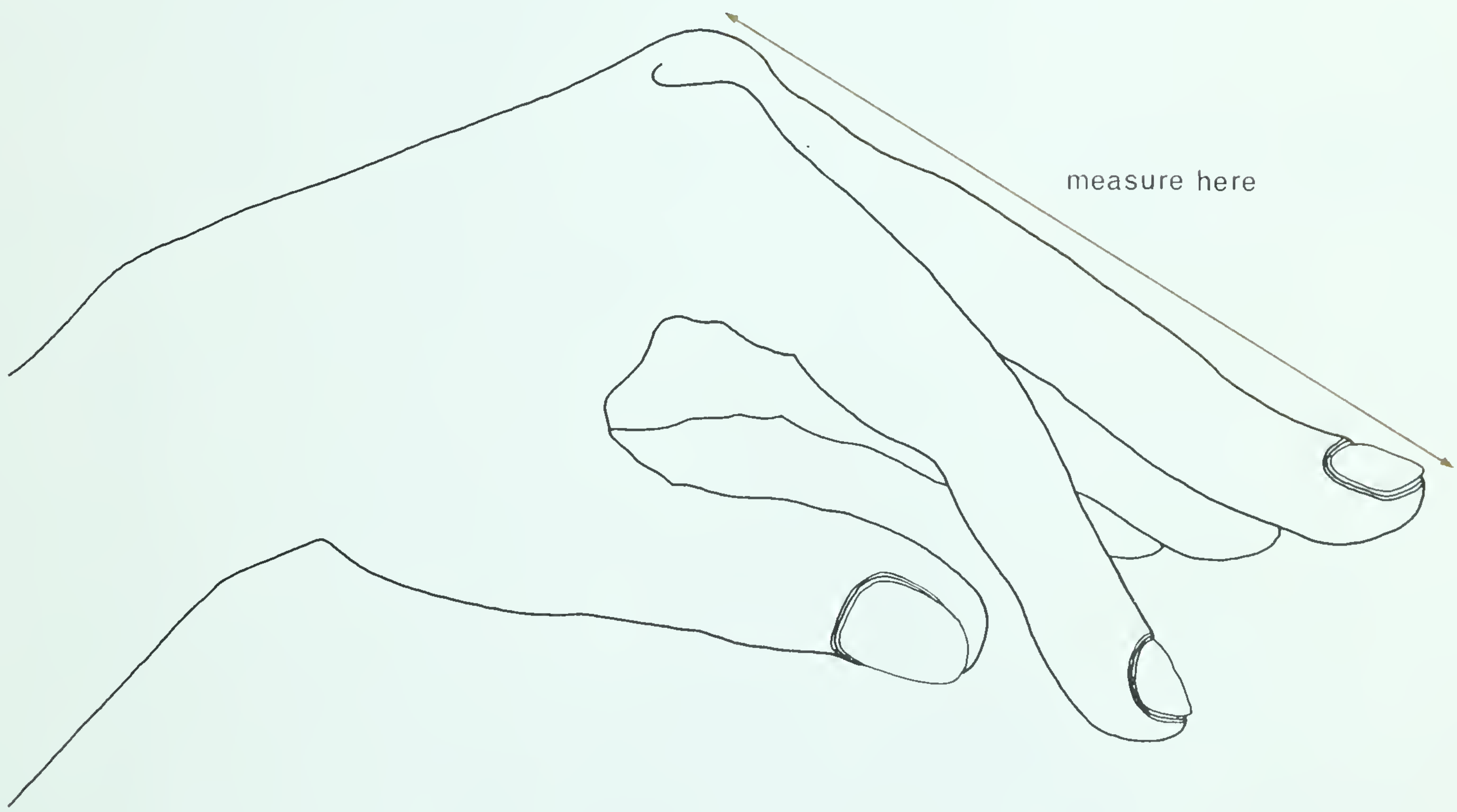


Figure 31
How to measure the length of your middle finger.

1. Bend all your fingers as in the diagram in figure 31 and, with your ruler, measure in centimetres the distance between the centre of the knuckle of the middle finger, not to the end of the nail, but to the tip of the finger itself, as in the diagram.

2. Now get ten members of your class to measure their middle fingers in this way and give you the measurements in centimetres. When you have written them all down, you may find that two or three, or more have the same measurement.

3. So now you can construct a chart, using your own set of figures. Suppose that five members of the class have a finger length of 9 cm, three have a finger length of 8 cm, one has a length of 7 cm, and one

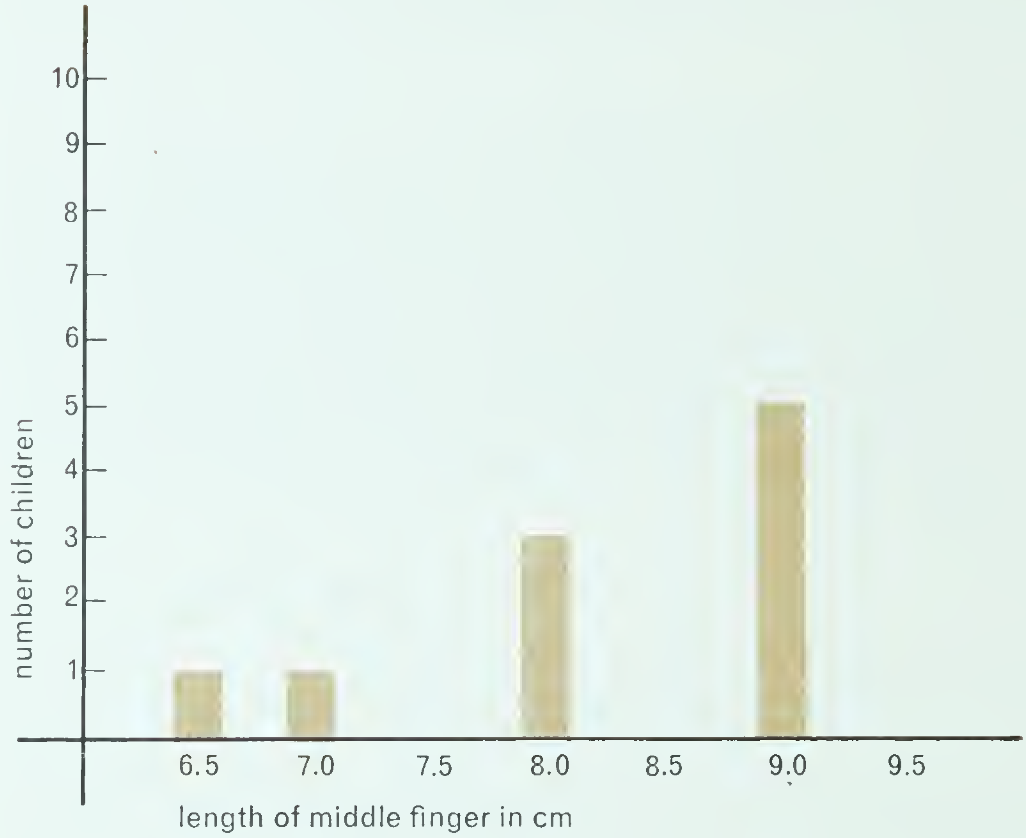


Figure 32
Bar graph to show how the length of the middle finger could vary in a few children.

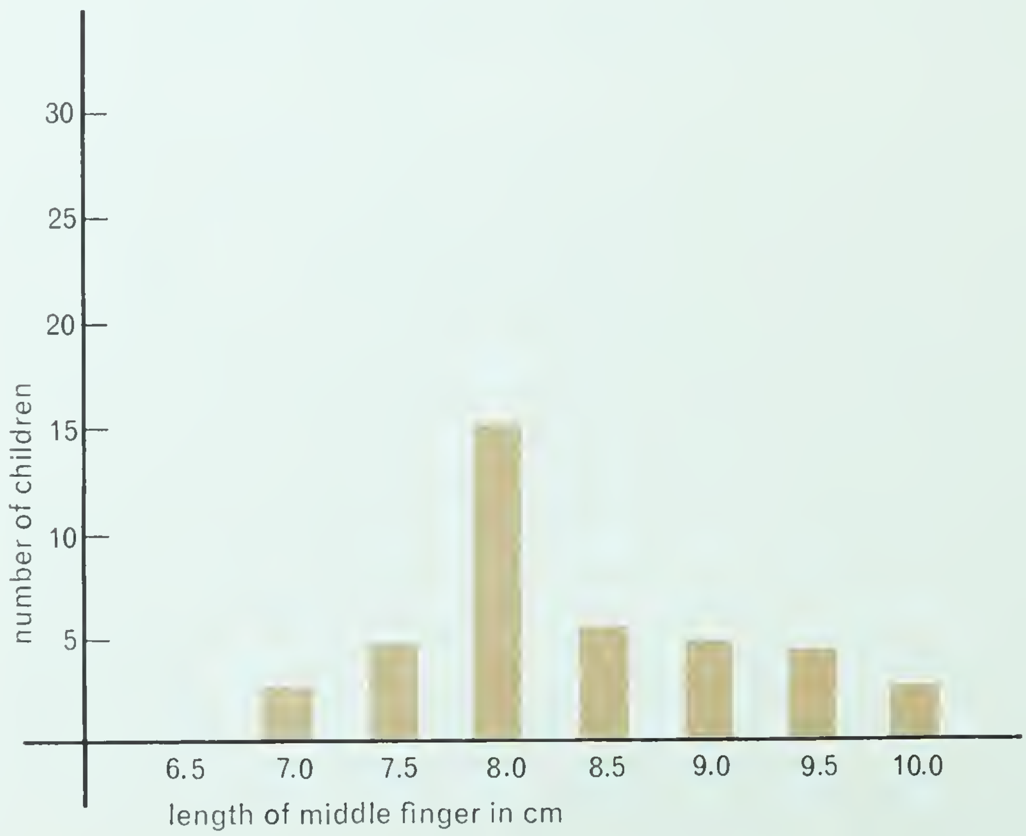


Figure 33
Bar graph to show how the length of the middle finger could vary in a class of thirty children.

of 6·5 cm. Each vertical block is placed along the horizontal line at the point where you have a measurement. Your chart (generally known as a bar graph) would look like the one in figure 32.

The bar graph shows that among ten children there are only four different finger lengths. By joining the top of the blocks together you get a rough curve.

4. Now try measuring the finger lengths of the whole class. Everyone in the class could measure their own fingers and collect the measurements from everyone else. If there are thirty in the class, you will probably get a greater number of different finger lengths than last time.

5. Arrange your results in the same way as before. The second bar graph may look like the one in figure 33 with a different shape of curve.

If you could take the finger lengths of, say, one hundred children, do you think you would get the same sort of curve as for the whole class ?

Look again at both of your bar graphs. How do they differ ? What is the average finger length of the whole class ?

If, instead of finger lengths, we were to record the height in centimetres of all the girls of the same age in a particular school, we should probably get the same kind of curve when the results were plotted. If several schools combined to give even more measure-

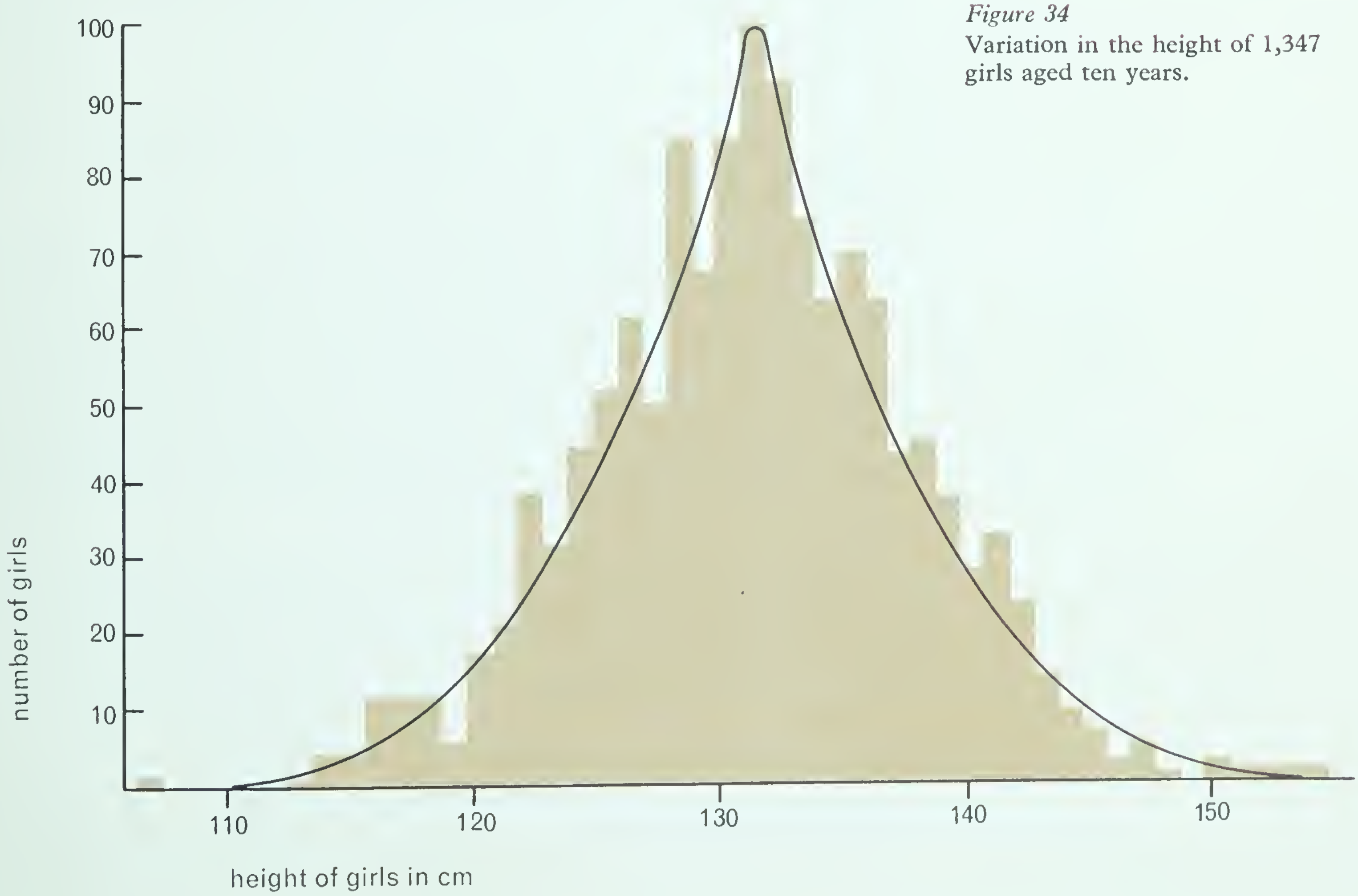


Figure 34
Variation in the height of 1,347 girls aged ten years.

ments, we might get a steeper curve still. Figure 34 shows a bar graph for the height of 1,347 London school girls aged ten. From this we see that the average height of the girls aged ten, is 132 cm. If we were to measure 1,347 boys aged ten, we might find that their average height was different from that of the girls.

If the children had not all been of the same age but of various ages, and if some had been girls and some boys, would this have given as much useful information?

What we have really shown by these graphs is that, for any characteristic such as finger length, there is an average. It is just the same as for the appearance of our twigs (section 3.13). But, provided we have made enough measurements, there is considerable variation on either side of that average.

Summary

Using a key to find out the names of the winter twigs has meant that you have had to look carefully at the twigs in order to decide what were the size and the shape of the leaf scars and what was the colour of the bud scales.

The key only helped with identifying the twigs of five kinds of tree. It might have been a much longer key, including all the species of trees growing in England.

As a beginner, you should always check the identification of a particular plant or animal made by means of a key. This can be done by looking up its description and picture in a good reference book.

By investigating some of our own characteristics we have shown several things:

a. There are many ways in which one person varies from another. When one characteristic, such as finger length, is measured, we get a number of different measurements even among pupils in the same class.

b. The chart in figure 32 shows the importance of getting a great many results in order to obtain a more reliable average. It also showed that the method we use in selecting a *sample* of the population is important. First we must decide what sort of information we wish to obtain. In our sample we were concerned only with girls of ten. We could have added a sample of boys of fourteen. But the bar graph we plotted would then have been less useful, for by looking at it, we could not have told which parts referred to boys and which to girls.

Later on you will be making other investigations which will involve sampling populations of animals or plants. The same principles will apply to them as have applied to human beings.

Cells as units of life

4.1 Looking at the structure of living things

When a biologist wishes to study a new plant or animal one of the questions he is likely to ask is 'What is its structure?' This can be answered in various ways. The biologist may want to know about the chemicals of which the living thing is composed. He may be looking for the larger units which make up the body of the organism in the way that bricks make up a house when they are put together. Many different kinds of buildings can be constructed from the same kind of bricks so it is possible that the great variety of living things which we studied in detail might have some sort of building units in common. If you examine the cut end of a tree trunk with a hand lens, you may just be able to see that the wood is made up of a large number of tiny separate ring-like structures. But this tells you little about its real composition. For that you must use higher magnification.

4.2 The use of a microscope

To see objects which are very small you have to use a microscope. Scientists have always been interested in the structure of living things but have not always had the instruments with which to see the units of which living things are built. The kind of microscope we use today was first made by Robert Hooke (1635–1703). He described his microscope in his book *Micrographia*, which includes many illustrations of objects which he had seen with the aid of this instrument (figure 35). Figure 36 shows Hooke's drawing of a flea. In one chapter we find the following account of his examination of a piece of cork:

'I took a good clear piece of cork, and with a Pen-knife sharpen'd as keen as a Razor, I cut a piece of it off, and thereby left the surface of it exceeding smooth, then examining it very diligently with a *Microscope* methought I could perceive it to appear a little porous; but I could not so plainly distinguish them, as to be sure that they were pores . . . I with the same sharp Pen-knife, cut off from the former smooth surface an exceeding thin piece of it, and placing it on a black object Plate, because it was itself a white body, and casting the light on it with a deep *plano-convex Glass*, I could

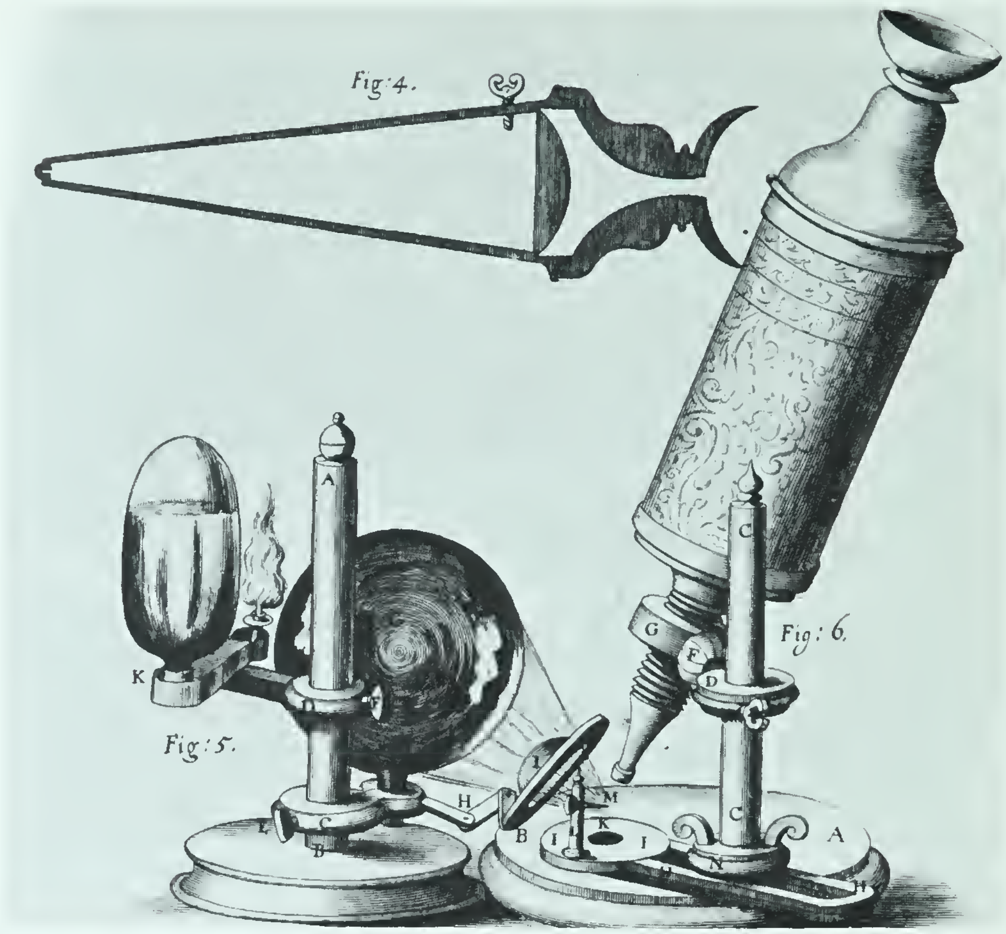


Figure 35
Robert Hooke's microscope. The numbers in the picture refer to the following parts: *Fig. 4* The body of the microscope.
Fig. 5 The lamp with a globe and lens to concentrate the beam of light on the object M. *Fig. 6* The microscope on its stand with screws G and F to alter the distance between lens and object and D to clamp it in position. *Photo by Wellcome Historical Medical Museum.*

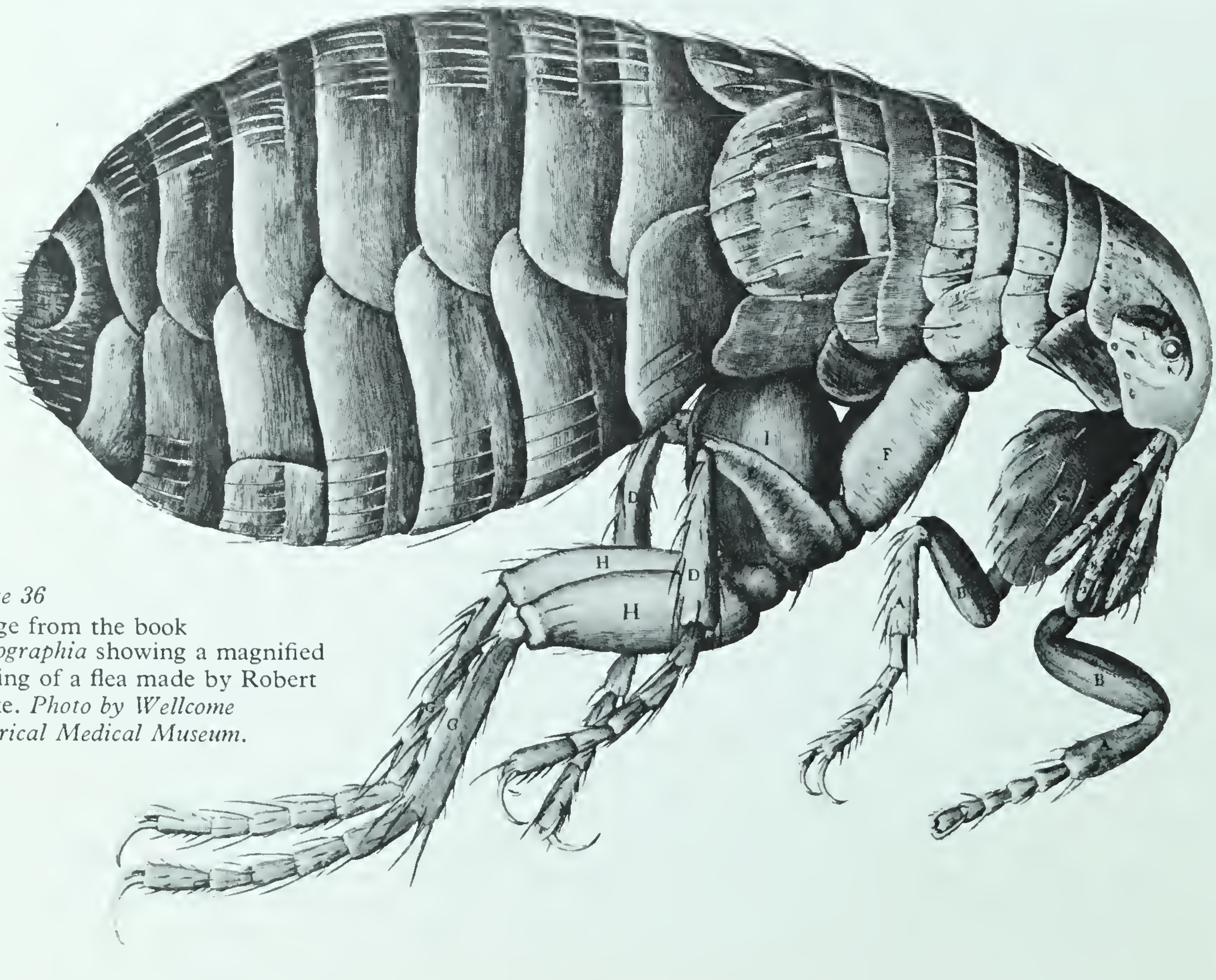


Figure 36
A page from the book *Micrographia* showing a magnified drawing of a flea made by Robert Hooke. *Photo by Wellcome Historical Medical Museum.*

exceedingly plainly perceive it to be all perforated and porous, much like a Honey-comb, but that the pores of it were not regular . . . these pores, or *cells*, were not very deep, but consisted of a great many little Boxes . . . Nor is this kind of texture peculiar to Cork only; for upon examination with my *Microscope*, I have found that the pith of an Elder, or almost any other Tree, the inner pulp or pith of the Cany hollow stalks of several other Vegetables: as of Fennel, Carrets, . . . Teasels, Fearn . . . &c. have much such a kind of Schematisme, as I have lately shewn that of Cork.'

His drawing of cork cells is reproduced in figure 37 and you can compare it with a photomicrograph taken through a modern microscope (figure 38).

Hooke not only described and drew these 'cells', he also measured them: '. . . I . . . found that there were usually about threescore of these small Cells placed end-ways in the eighteenth part of an Inch in length, whence I concluded there must be neer eleven hundred of them . . . in the length of an inch, and therefore in a square inch above a Million, or 1166400, and in a Cubick Inch above twelve hundred Millions, or 1259712000 a thing most incredible . . .'

Robert Hooke was the first 'curator of instruments' of the Royal Society, which received its royal charter in 1662.

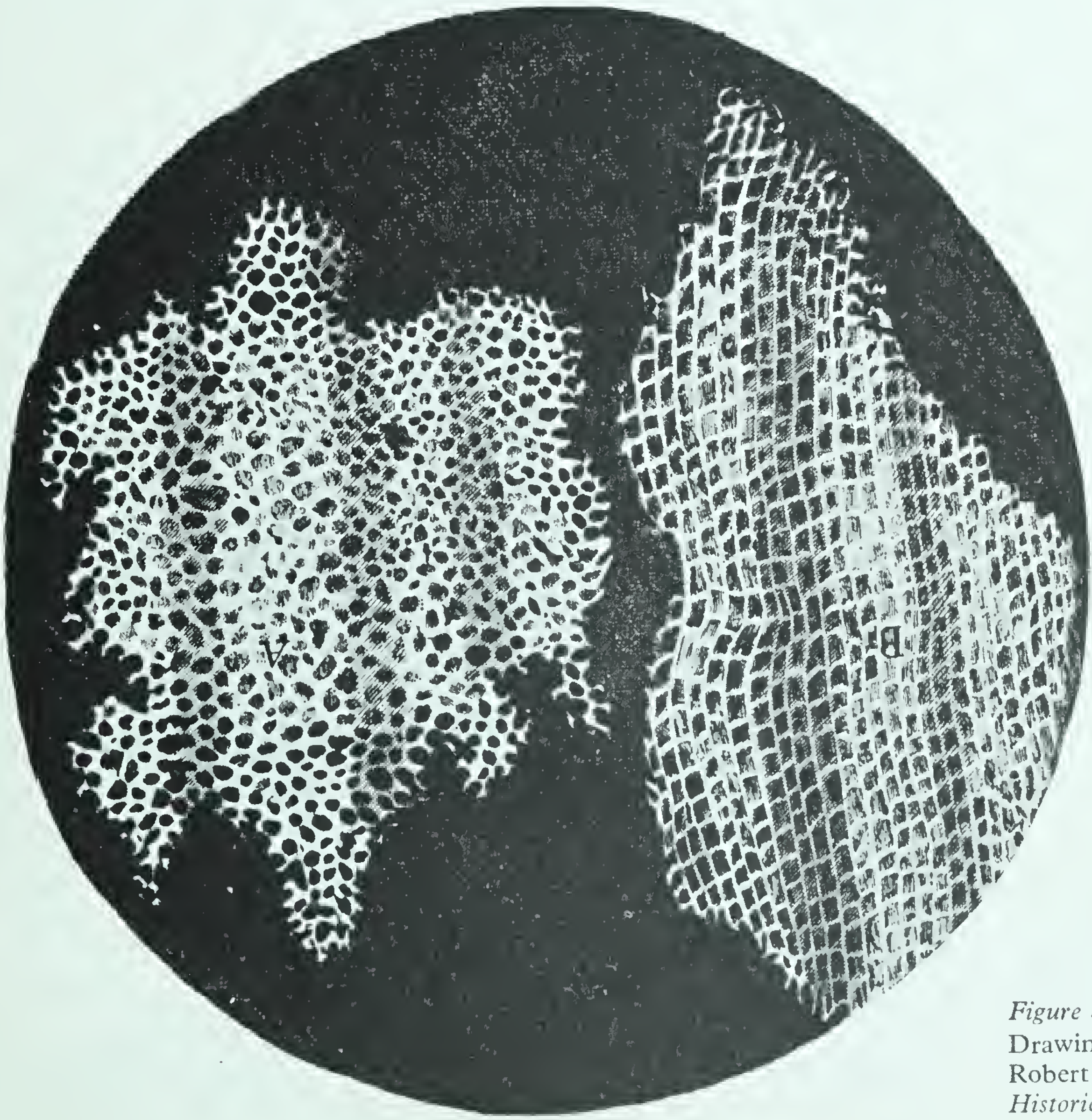


Figure 37
Drawing of cork cells seen by Robert Hooke. *Photo by Wellcome Historical Medical Museum.*

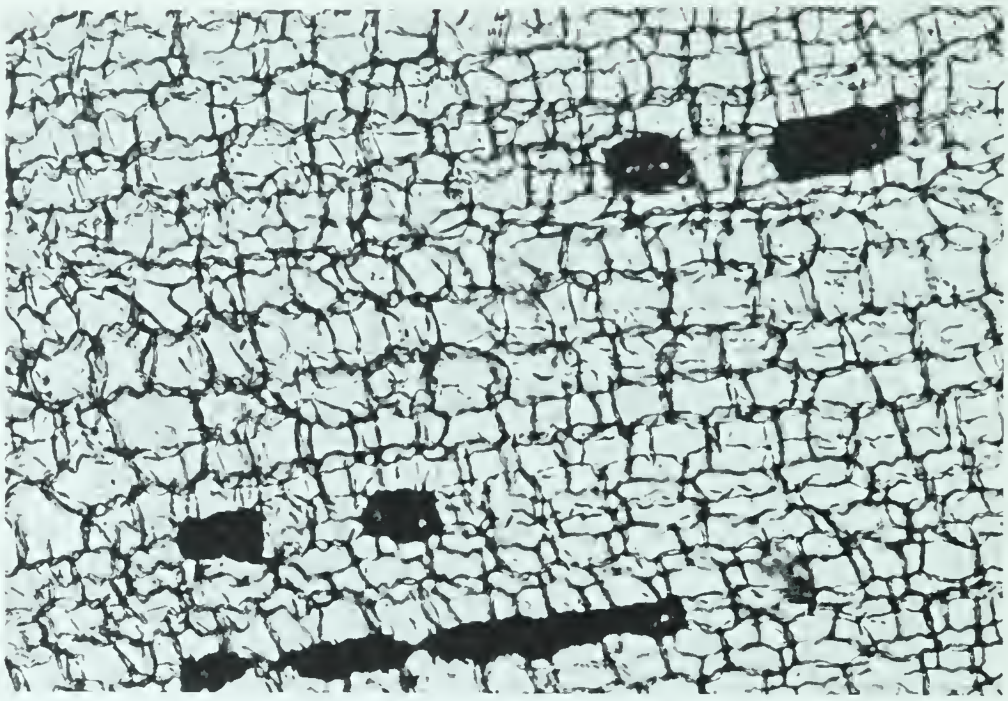


Figure 38
Photomicrograph of cork cells.

Even the cheapest microscopes we use today are much better than Hooke's instrument. Nevertheless, his instrument made possible one of the most important advances in our knowledge of the building units of living things.

4.21 The parts of a microscope

Microscopes vary in design but all rely on one principle for producing a magnified picture or image. In some ways this principle is similar to that you have already used in working with your hand lens. A compound microscope is designed to carry out two of these magnifications, one after the other. In other words, there is a first lens, the objective, to produce a magnified image and then a second lens, the eyepiece, to magnify this image still further. The clearness of the image is of equal or more importance than the magnification.

For many years the usual arrangement for lighting and focusing was to have a platform (stage) fixed to the body of the instrument and a tube to hold the lenses which moves up and down for focusing (figure 40). More recently, microscopes have been produced with the tube fixed in one position and a stage which moves up and down instead (figure 39).

The essential parts of a modern microscope are as follows:

a. A metal 'body' which forms a base to which the other parts are attached. Always lift a microscope by grasping the body of the instrument.

b. A stage to hold the slide with a central hole to let the light through.

c. A light below the stage or a mirror to reflect light.

d. A tube to hold the lenses and keep out all light except that which comes from the object being viewed.

e. Objective: the lens at the lower end of the tube. Different magnifications can be obtained by changing objective lenses and many microscopes have a rotating turret or nosepiece to hold three or four different objectives.

f. Eyepiece: the lens in the top of the tube through which you see the image.

See if you can find all these parts in figures 39 and 40 and on your own microscope as well.

To get the best use from a microscope you must learn how to adjust it and how to prepare objects for viewing. With your hand lens or binocular microscope you will have been looking at the surfaces of objects. So long as they were well illuminated, the light reflected from them allowed you to obtain a clear picture, at least when the instrument was focused.

The much smaller objects for which you use a compound microscope of the type Robert Hooke designed are best seen if you view them by light passing through. This means that you can only look at very thin things which are nearly transparent, or at thin slices of larger objects. You would not find it easy to cut a thin slice

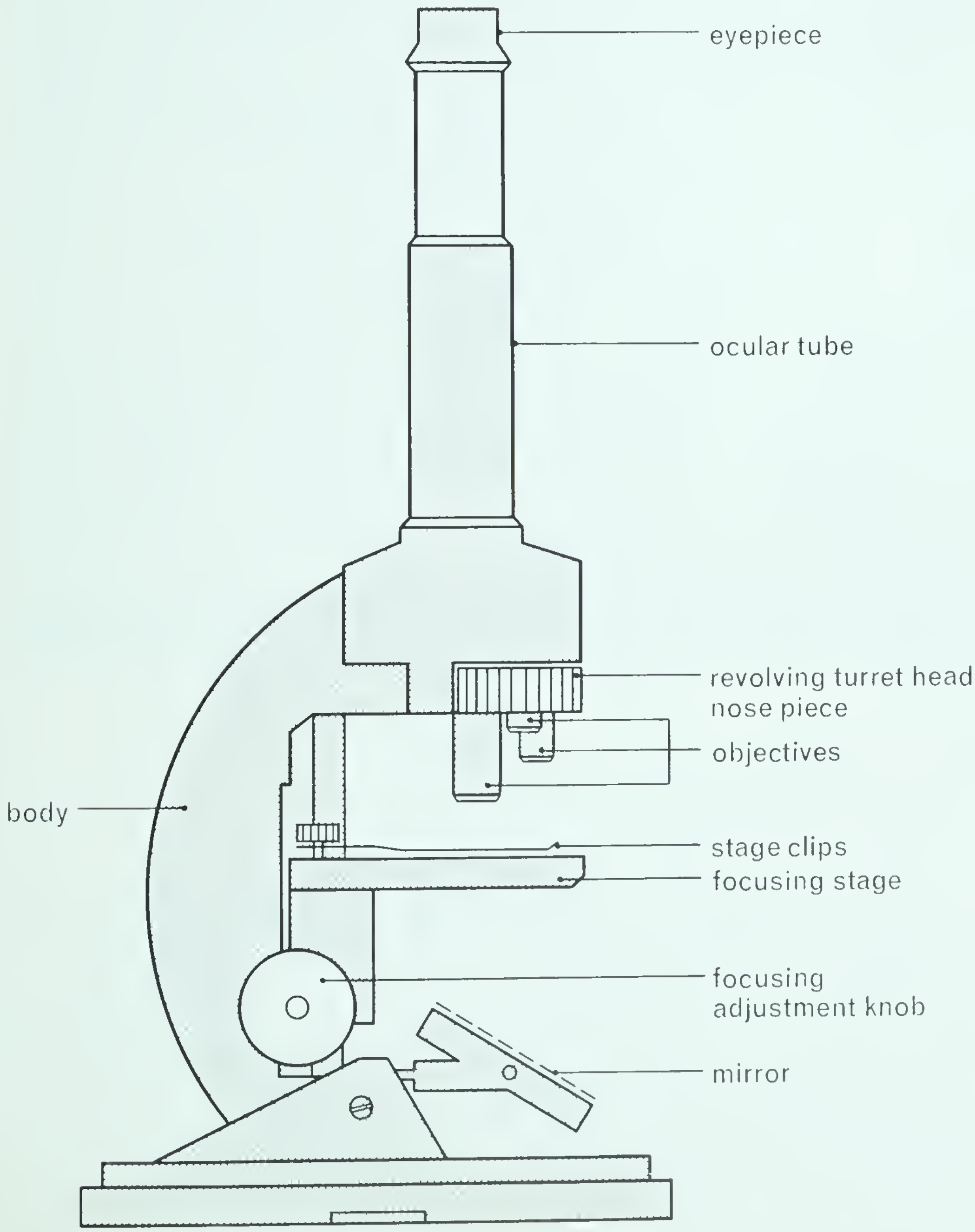


Figure 39
Side view of Meopta A.Z.1. microscope with main parts labelled. The stage of this microscope moves up or down for focusing.

of a bean root for yourself but later on you will see a prepared slide which has been cut on a special machine (microtome).

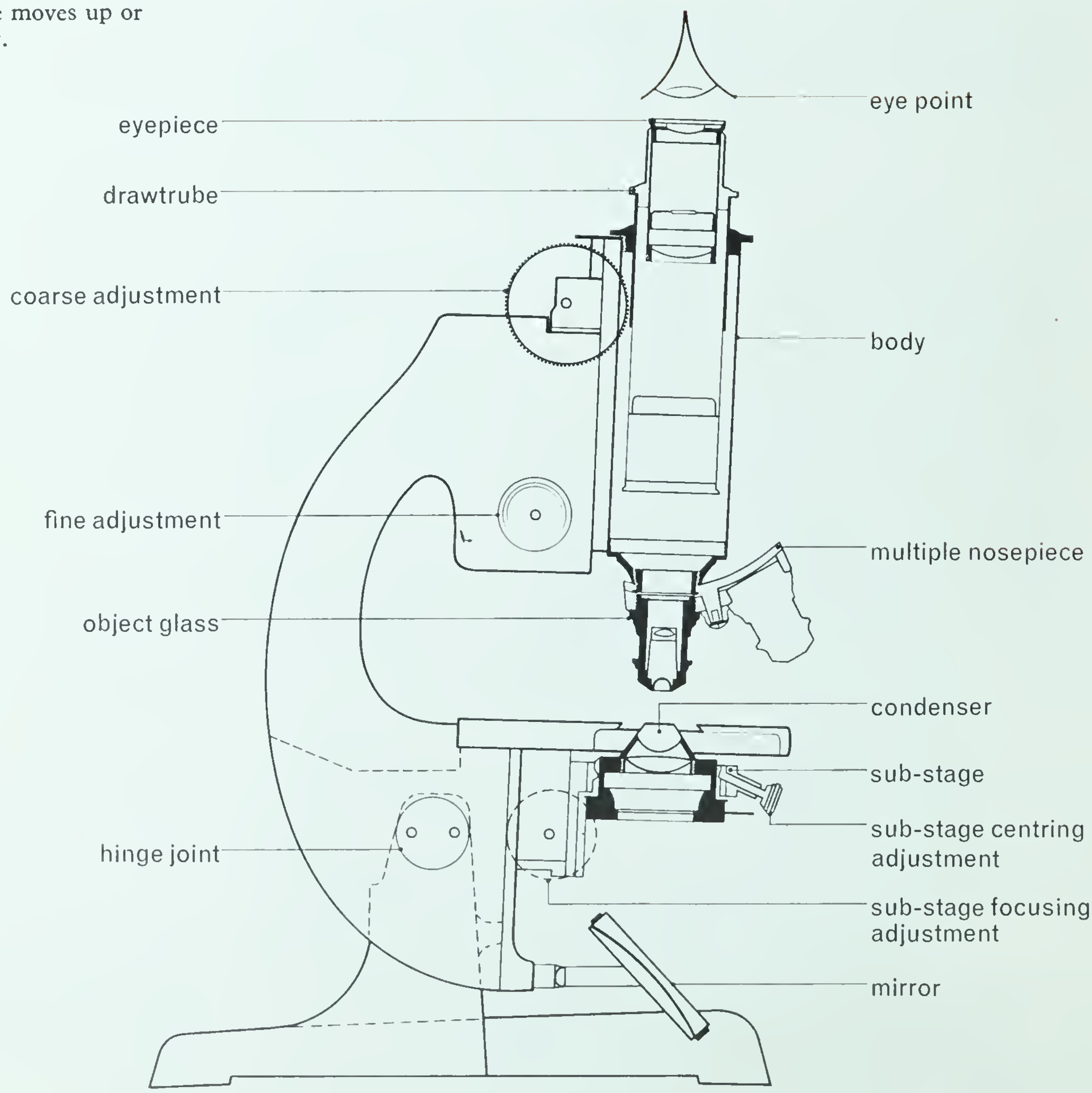
A small root such as the first growth from a mustard seed is thin enough for you to examine in another way.

4.3 Examination of a mustard root squash under the microscope

Look at a mustard seedling which has been growing in a damp atmosphere (figure 41). You will see that much of the root is covered by fine hairs.

1. Cut off the last $\frac{1}{4}$ inch of root (see figure 42).
2. Place it in a drop of water on a microscope slide.
3. Touch the edge of the drop with a glass cover-slip held up by a needle.
4. Lower the cover-slip gradually onto the drop of water and the

Figure 40
Side view of Beck London 47 with main parts labelled. The body of this microscope moves up or down for focusing.



root tip. The root is quite thick so the slip will rest on top and the water will not run out far to the side.

5. Now wrap the slide in blotting paper and tap with a pencil or press gently on the cover-slip just over the root tip with your first finger.

6. As the root is squashed, the water will fill the whole space between the side and cover-slip and the root will now be transparent.

7. You must now arrange your microscope in the best way to see the slide.

4.31 Adjusting your microscope

First the lighting must be arranged correctly. With those microscopes which do not have a light built in, a mirror is used to gather light and to reflect it into the lenses. Light from the sky (but not direct sunlight), or from a bench lamp, is satisfactory.

Figure 41
Mustard seedling in $2\frac{1}{2}$ inch plant pot showing root tips at the correct stage for making a preparation.
Photo, C. D. Bingham.

1. Arrange the mirror to reflect the light towards the stage.

2. Place your slide on the stage with the root near the centre of the hole.

3. Select the objective with lowest power – the one with the shortest mount and the widest lens.

4. Look at the side of the microscope and turn the coarse focusing knob to bring the objective as close to the slide as you can without the two touching. (Remember that in some microscopes the focusing knob moves the tube, and in others the stage.)

5. Look through the eyepiece and turn the focusing knob to move the lens away from the slide. *NEVER FOCUS BY MOVING THE LENS TOWARDS THE SLIDE WHILE LOOKING THROUGH THE EYEPIECE.*

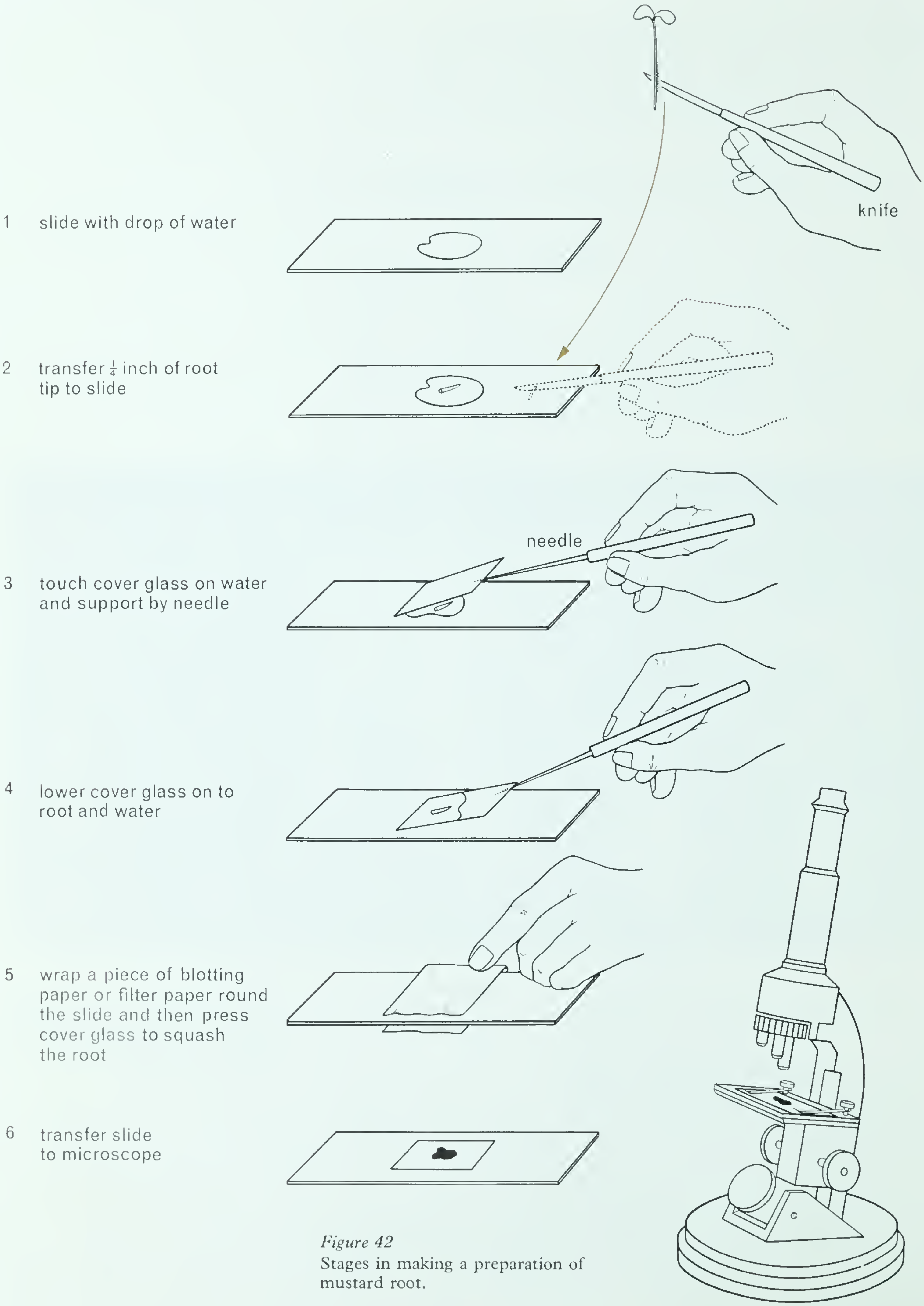


Figure 42
Stages in making a preparation of mustard root.

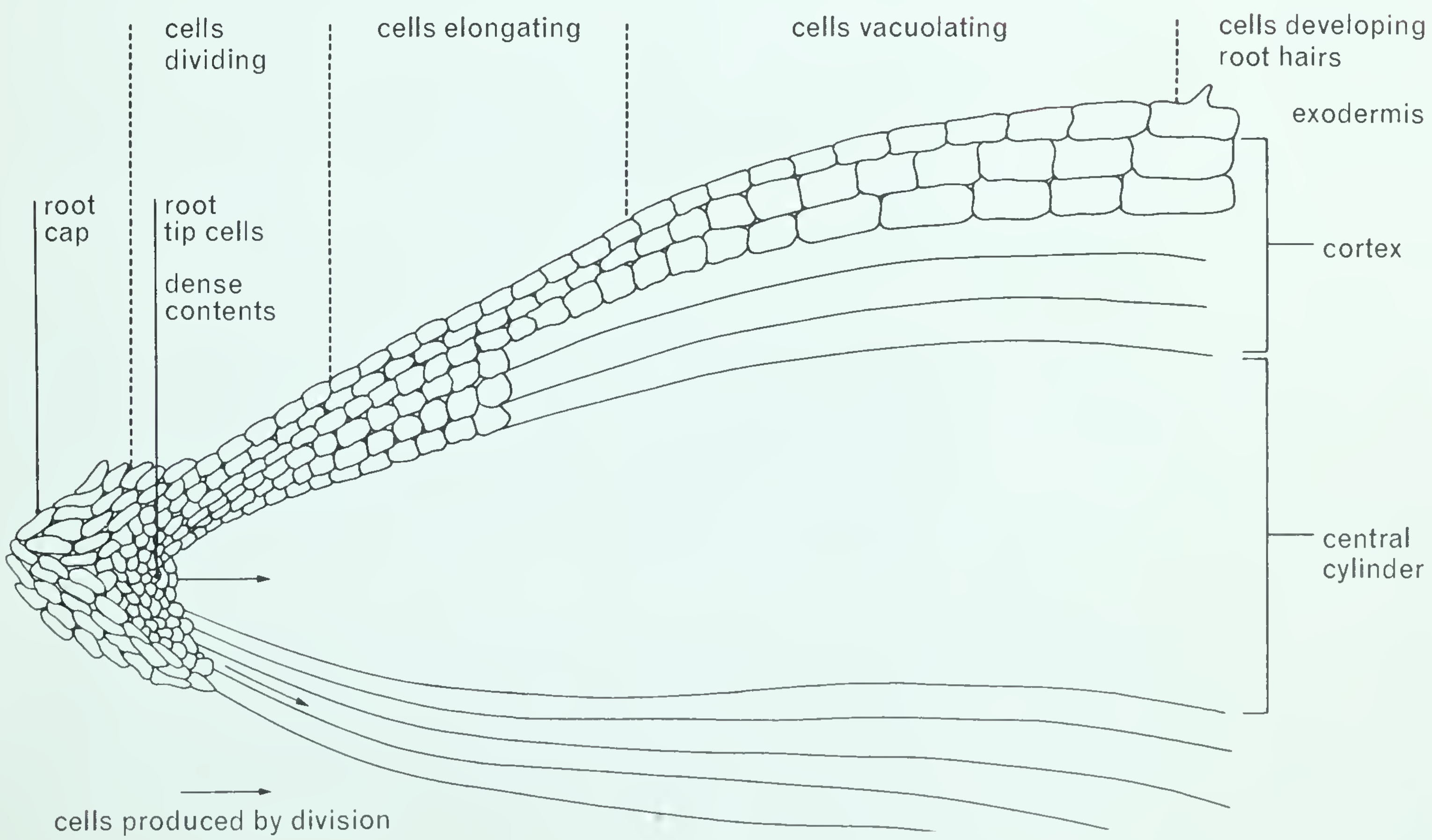
If you do move the lens and slide towards each other and miss the focus point, you are likely to crush the slide and lens when they meet. This can be an expensive mistake! But if you miss the focus while you are moving the slide and lens away from each other, you will merely reach a point at which the tube will travel no further. Do not try to force the knob beyond this point. Start again by bringing objective and slide close together and then move them apart a little more slowly and look more carefully. You should eventually reach a point where you see a clear picture through the eyepiece. Try to keep both eyes open while you look down the instrument.

6. At this stage check on the lighting by removing the eyepiece and looking down the tube at the back of the object lens. This should be evenly illuminated and should be three-quarters filled with light. If you cannot get this right by moving the mirror, ask for help. Unless the lighting is correct you will not get the best results. Keep the eyepiece in your hand or in a safe place and not on its side where it can roll.

7. Now replace the eyepiece and examine the slide of the mustard root. When you try to move the slide to a new part you will find another difference between the hand lens and the compound microscope. The object and image move in opposite directions. This you will have to get used to.

The most obvious thing in your preparation will probably be air bubbles: these appear as black, curved lines. Some of the bubbles may be mixed up with part of the root so choose an area that is clear

Figure 43
Diagram of cells of a squashed root tip.



of them. You will see that the root is composed of box-like units similar to those shown in figure 43. These are *cells*. The contents of the cells are nearly transparent so that you cannot see them clearly. Then many cells are likely to lie on top of each other.

Record what you can see by a drawing of a few of the cells. Make the drawing large enough to show all the details you can find.

Are the cells all the same shape ? Where are the largest cells and where are the smallest ? Do the cells all appear to be the same shade of grey ? Cells look darker because they let through less light.

To examine cells more clearly you need a very thin slice. The cells in a section can be made much clearer by staining their walls and the contents with different dyes. It would be difficult for you to cut and stain a section of root so you will be provided with a permanent slide ready made.

4.4 Examination of the cells of a broad bean

1. Choose a part of the section you can see clearly and examine one cell. Does the material forming the box look the same as the rest of the cell ? The outside of the box is called the *cell wall*. The substance which forms the living part of all cells is called *protoplasm* (Greek: *protos* = first; *plasma* = anything formed or moulded). Protoplasm is a general term for the cell contents and you will have to use more precise names for the parts of a cell later on.
2. Look for one special part of the protoplasm. This is different from the remainder of the cell, is often in the middle and takes up more stain. It is known as the *nucleus* (Latin: *nucula* = a little nut) and the remainder of the protoplasm is called *cytoplasm* (Greek: *kytos* = hollow vessel, cell).
3. In the largest cells look for clear spaces with no cytoplasm. These are filled with a liquid called cell sap and are known as *vacuoles*. You will be looking at these cells again later, using a greater magnification to see more of their contents. In the meantime let us see if animals possess cells like those of plants.

4.5 Do animals have cells ?

We can most easily answer this question by examining material from ourselves. There is no need to cut sections, for in some parts of our body the surface is being continually added to from within, and where the outer part is being rubbed away. The skin is a good example of this, and the moist lining of your cheek is a useful source of material to examine.

4.51 Examination of cheek cells

1. Scrape gently the inside of your cheek with your finger nail.
2. Touch the surface of a clean microscope slide with your finger tip so that a drop of saliva is transferred to the slide with the cheek scrapings.

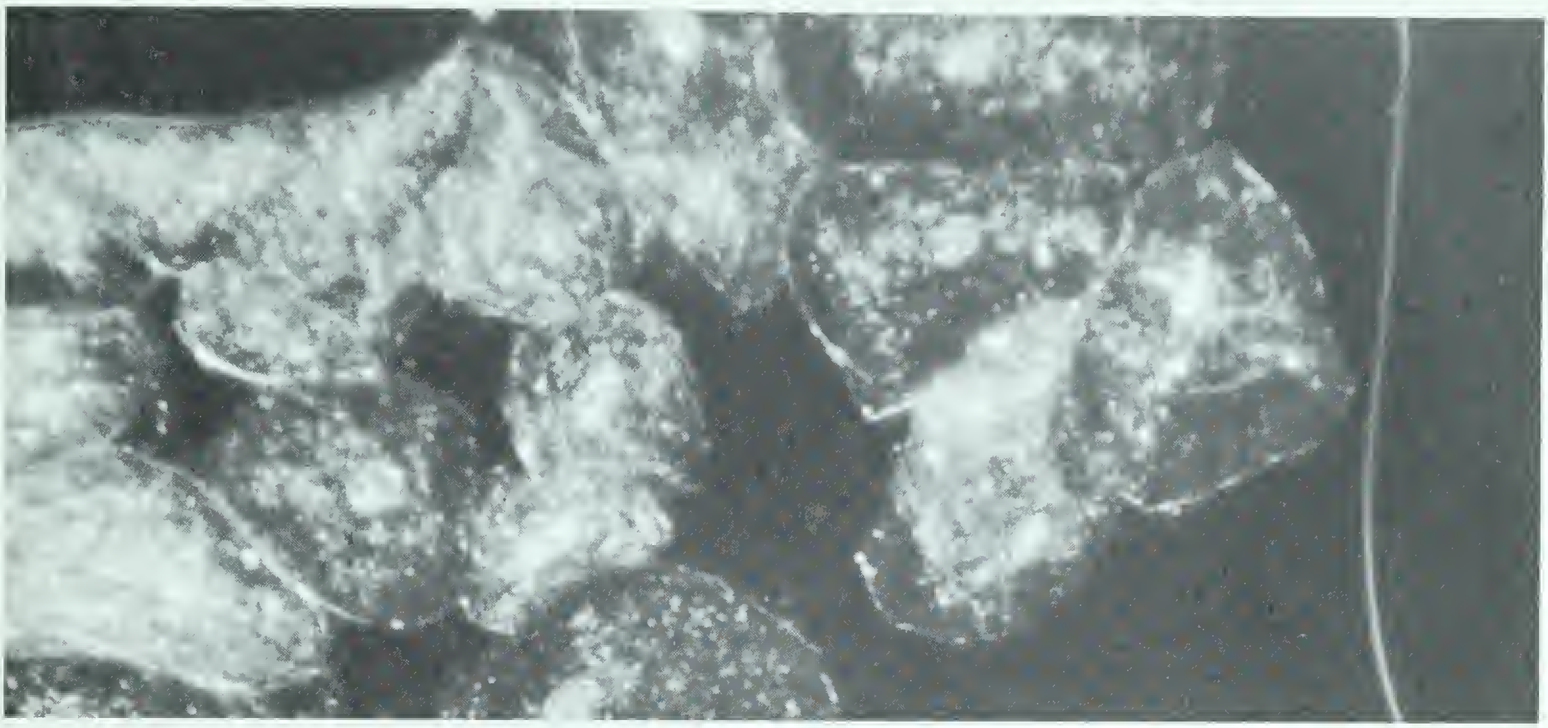


Figure 44
Cheek cells under low power.
Photo by Gillett and Sibert.

3. Cover this with a thin glass cover-slip to prevent it drying up. It also protects the microscope objective from touching the specimen and gives a flat upper surface for clear vision.

4. Lower the cover-slip as you did in the experiment 4.3.

Another easy way is to place the cover-slip on a clean piece of white paper. Invert the slide so that the saliva drop hangs downwards and then pick up the cover-slip by lowering the slide and droplet until it just touches the cover-slip. When you examine the preparation under low power you will again see air bubbles; but in the liquid part outside the bubbles look carefully for objects similar to those in figure 44.

They are almost completely transparent when viewed by ordinary lighting and this makes them difficult to see. To improve visibility try holding a pencil between the mirror of the microscope and the stage so that the direct beam of light is interrupted. If this is done carefully you will see the cells as bright objects on a black background and their structure should be clearer.

Which structures in these animal cells resemble those in plant cells? Have cheek cells a cell wall? The outer boundary of the cytoplasm where it meets the water and which prevents the water and protoplasm mixing is called a *cell membrane*. This is part of the protoplasm and is not a separate structure outside the cell as is the cell wall of plants.

4.6 How much does the microscope magnify?

You have seen a number of cells under the low power of the microscope. How much have they been magnified?

When you look down a microscope you have nothing to compare with the object to give you an idea of size. Normally you judge the size of a thing by comparing it with other things around it. The picture you see when using a microscope could be of a very small object magnified many times or of a larger object not magnified as much. As you cannot see individual cells without a microscope you cannot judge how big they are.

Having some sort of scale becomes even more important when you use different powers of magnification. A convenient object to look at through the microscope is a ruler with a mm scale.

1. Remove the slide from your microscope and replace it by a transparent plastic ruler with 1 mm graduations or by a microscope slide on which lines have been scratched 1 mm apart.
2. Now measure the width of the field of view of the microscope. As this is only a few millimetres, the size of cells will work out as awkward portions of a millimetre. To avoid this we use a smaller unit of measurement, the micron. It is written as the Greek letter μ (pronounced *mu*) and is one thousandth of a millimetre.

$$1 \text{ micron} = 1\mu = \frac{1}{1000} \text{ mm or } 0{\cdot}001 \text{ mm.}$$

3. Convert the diameter of the field from millimetres to microns, then estimate how many cells would just stretch across the field if placed side by side.
4. Divide the diameter of the field by this number to find the size of a cheek cell.

To obtain a higher magnification you must use a different objective lens. Your microscope will probably have several objectives on a revolving nosepiece, and it should be possible to swing the higher power into position and still keep the object in focus.
5. Measure the width of a field (in microns) for each objective used so that you can have some idea of the size of the cells you see.

4.61 Detailed examination of cheek cells

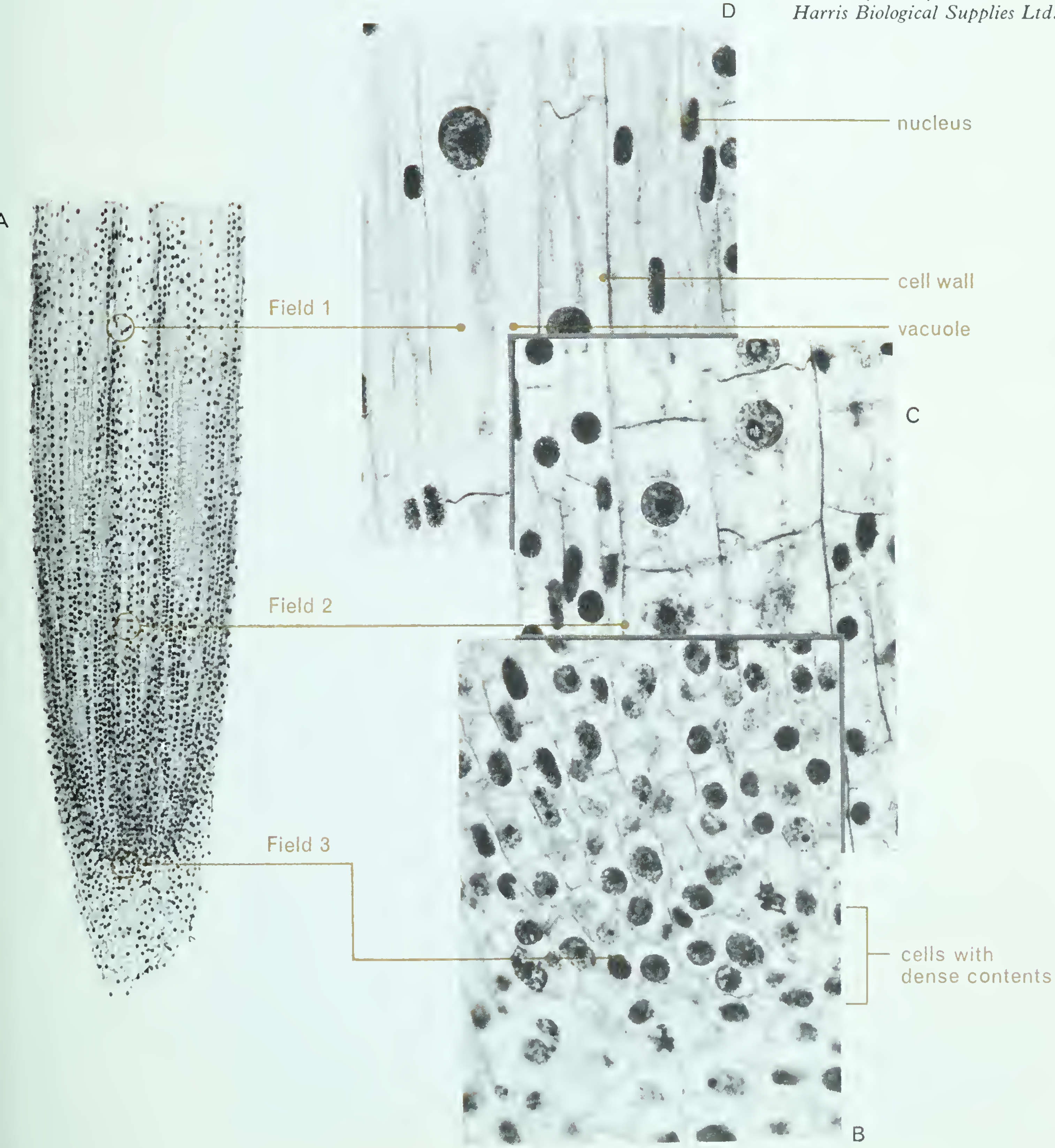
Look at cheek cells on a slide with the higher power lens in position. If the structures inside the cell are not easy to see you can improve the image by staining the cell. Try putting one drop of a dye, methylene blue, at one side of the cover-slip and drawing it under by touching the other side with torn blotting or filter paper. How do these cells differ from those you saw in the mustard root?

4.7 Examination of a prepared section of a broad bean root

With your microscope examine, under both low and high power, a permanent preparation of a section of a bean root cut lengthwise. Near the tip you should be able to see many densely packed cells, each with a nucleus clearly visible.

You will have found a great number of cells in the roots of mustard and bean seedlings. Where did they all come from? How did the root begin? The answer is that all cells, particularly when they are young, are capable of producing new cells simply by dividing in two. When they are fully grown, the products of each division then divide again and before long there is a mass of cells all close together such as those you have seen with your microscope. It is unlikely that you will be able to detect on your slide cells actually in the process of dividing (undergoing *cell division*), but

Figure 45
Photographs of a longitudinal section of broad bean root tip.
A. (× 30).
B. Young cells in the process of dividing (× 350).
C. Cells growing larger (× 350).
D. Cells which have grown even larger by the development of a vacuole (× 350).
Harris Biological Supplies Ltd.



you can easily see the process on a film which is very much speeded-up, so that a few minutes correspond to several hours.

4.8 Cells and growth in a bean root

When cells divide into two halves without any increase in size, would you expect there to be an increase in size of the root? This process is taking place in region B of figure 45. What effect will the increase in size of cells between region B and region D have on the length of the root?

Figures 46 and 47 show a broad bean seedling which has been marked at 1 mm intervals from the tip backwards. Figure 48 shows the same bean which has been allowed to grow for four days after it was marked. Compare the position of the marks and note where growth has taken place. Look again at figure 45. Can you explain *how* the root of the bean seedling has grown longer?

Summary

Living things vary in size from the very large to those which are invisible to the naked eye. If they are made of common units of structure, these must be very small indeed. A microscope is used to examine living things and to look for these units.

The units are called cells. They make up the bodies of plants and animals. Plant cells have a cell wall and protoplasm. There is a space in the protoplasm, called a vacuole, which is filled with fluid, and there is also a nucleus. Animal cells have protoplasm and a nucleus but no cell wall.

Cells divide in such a way that each part becomes a new cell which increases in size. This is how growth occurs. Growth in the length of a root takes place in the region behind that in which cells are dividing and where each cell is increasing in size.

Background reading

The story of the microscope

The microscope was invented in Europe probably a little before 1600. No one is sure exactly where or by whom. But its invention was one of the great discoveries of the Renaissance. The Renaissance was a time of great change when many new ideas and theories were born. Men, such as Galileo, began to observe and question the nature of the world around them. And the microscope gave men a glimpse into a new world of the very small, just as the telescope had helped to unfold to men the secrets of the stars. Your first steps in learning science will take you along a path similar to the one taken by the early scientists. They made the most accurate and careful observations possible at that time. With the aid of the microscope they were able to see and wonder at things man had never seen

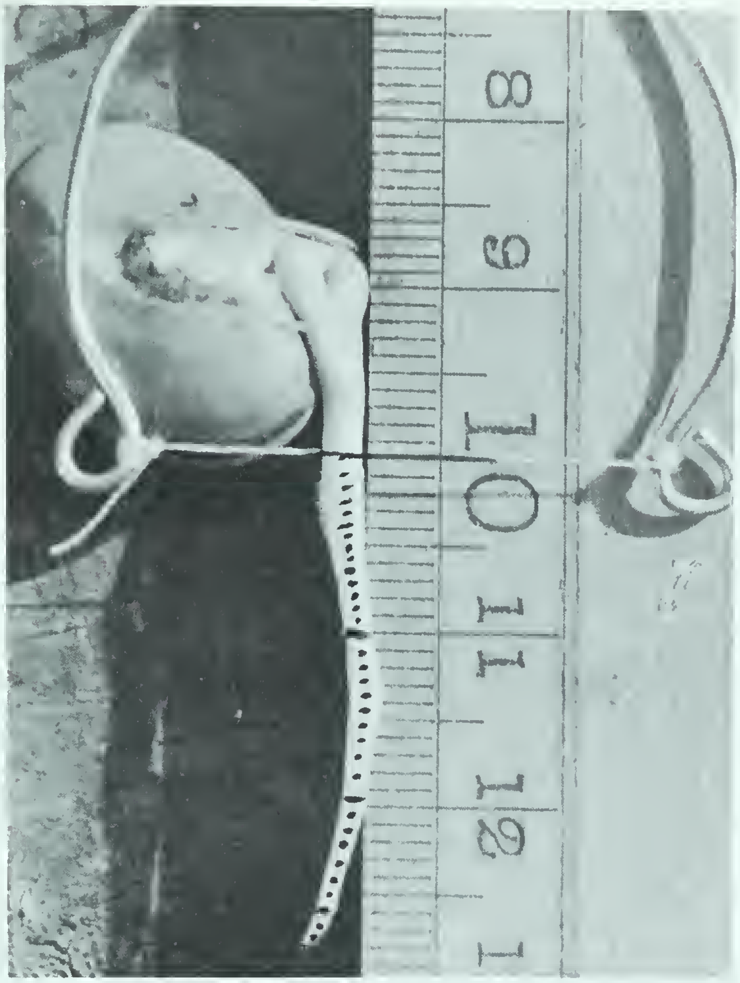


Figure 46
Bean seedling marked at 1 mm intervals. *Photo, C. D. Bingham.*

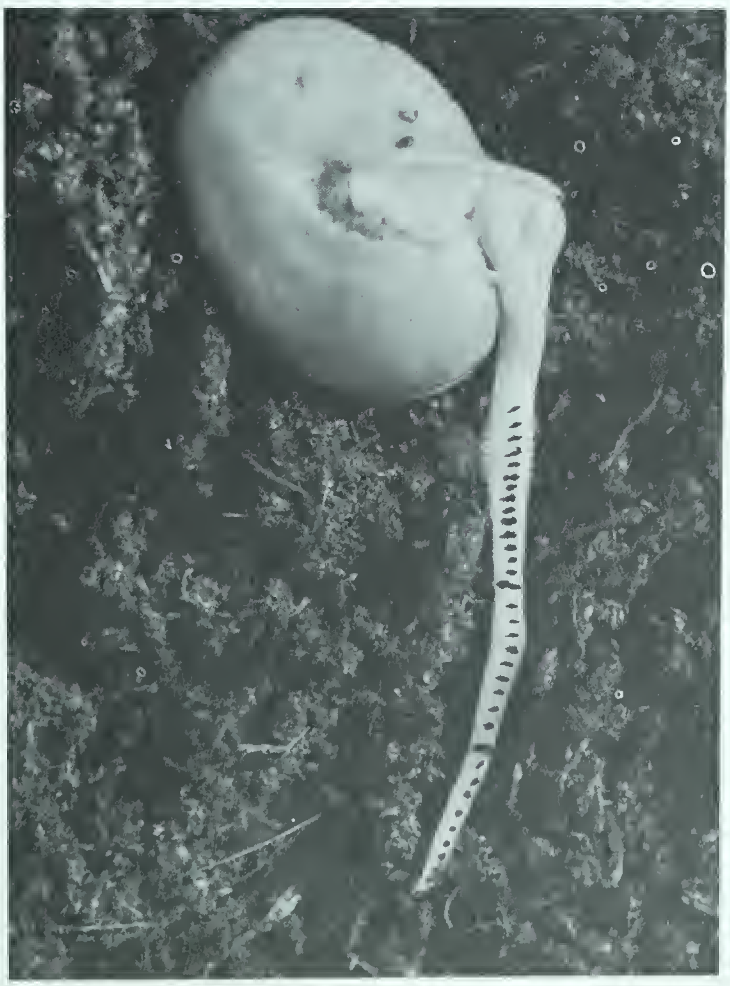


Figure 47
Marked bean seedling immediately after marking. *Photo, C. D. Bingham.*

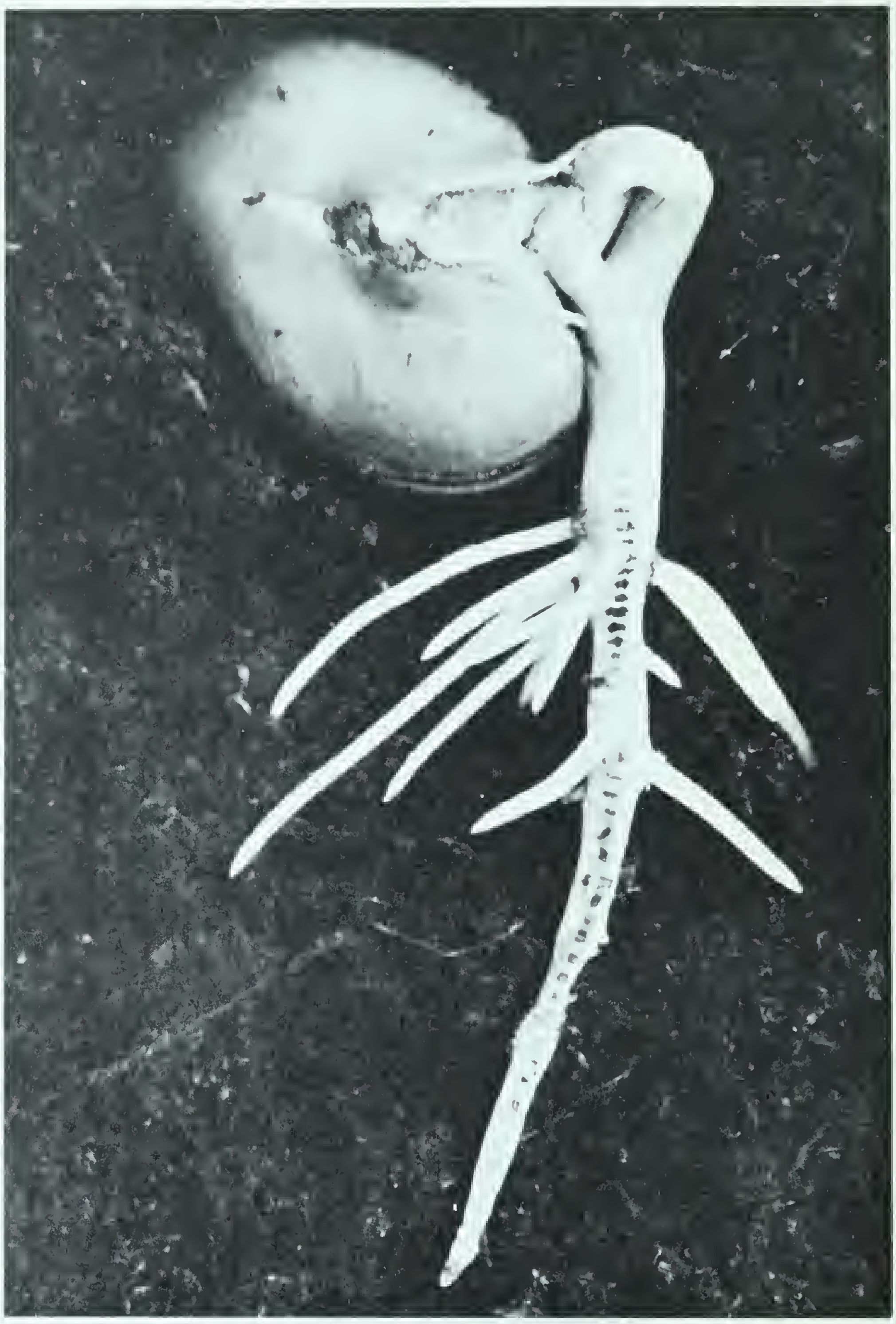


Figure 48
Marked bean seedling growing four days after marking. *Photo, C. D. Bingham.*

before: insects, tiny parts of plants, the very small creatures that live in ponds, and even the smallest of all living things then seen, germs.

Scientists made theories about what they saw through the microscope and argued about their theories. To settle their arguments they needed better microscopes that could magnify yet smaller things. But, unlike the telescope which was used from the beginning by sailors, the microscope had no real, everyday use for many years. It was looked on more as an amusing toy – not a scientific tool.

In Holland the atmosphere was favourable to the new ideas of the Renaissance. Around 1600 a Dutch spectacle-maker fixed one at each end of a short metal tube. When he looked through the tube

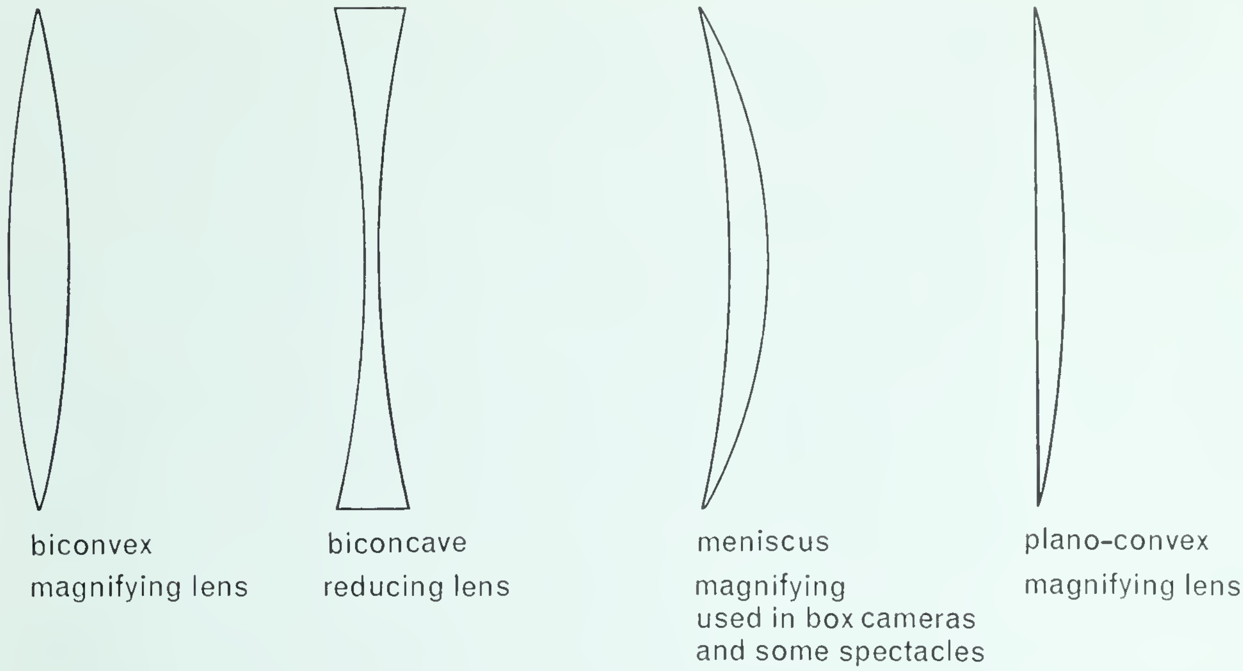


Figure 49
Four kinds of lens.

he saw things near the far lens startlingly magnified. Now lenses had been known long before this. A form of simple spectacles had been in use since 1400. A lens is a circular disc of glass, moulded and ground to make its two surfaces 'bulge' outwards. The surfaces are shown in figure 49.

Rumour of this Dutch invention with lenses reached Galileo in Italy. He used his knowledge of refraction – the bending of a beam of light as it passes from air through glass or water – to make his telescope with a concave lens (surfaces 'cave' in) close to the eye and a convex lens (surfaces 'bulge' out) further away. He applied for a patent in 1609. Early microscopes had a thin, slightly convex lens, called the eyepiece lens, close to the eye and a fat, strongly convex lens, called the objective lens, next to the object being looked at. The best of these microscopes could magnify up to thirty times.

But it was not easy to build microscopes that could magnify more strongly. For early lenses were crude. Very often the lens eyepiece magnified the faults produced by the objective lens, as well as its images. These faults are called aberrations. There are two types: sometimes the whole image is slightly blurred – spherical aberration – or frequently the image is surrounded by a coloured fringe – chromatic aberration.

In London Robert Hooke's microscope had these faults. But he improved upon the original Dutch design: the object was well lit and held in a fixed position on a sort of stage. Both lenses could be moved to vary the magnification of the microscope. For over a hundred years scientists used microscopes similar in type to Robert Hooke's.

A famous botanist Nehemiah Grew (1641–1712) was studying plants at the same time as Hooke was developing his microscope. They were both members of the Royal Society in London and used the same microscope. Using Hooke's microscope, Grew made drawings accurate enough to be included in a modern textbook.

Microscopes became popular and, crude as they were, many important discoveries were made, including that of the plant cell, the smallest building brick of living matter. Societies for the encouragement of the use of microscopes flourished, in which members compared notes on their findings.

In Delft, Holland, a linen draper called Anthony van Leeuwenhoek (1632–1723) invented a different type of microscope. He ground his own lenses to a special shape but kept his method a secret. A single lens was then mounted in a brass or silver plate. Objects were fixed close to the lens. Some of his microscopes – and he made more than two hundred – could magnify things several hundred times. Because his microscopes were so powerful, he was able to describe objects nobody else could see. He sent many reports of his findings to the Royal Society and utterly perplexed his fellow scientists.

Work with microscopes led to a most important basic idea in biology – the cell theory. This theory says cells make up all living things from men and trees down to all but the smallest germs.

The cell theory gave a new drive to the invention of stronger microscopes to see far smaller parts of living matter. One of these inventions is the electron microscope, made in Germany just before the Second World War. It was found that a beam of electrons could be used to produce far greater magnifications. The electron microscope could distinguish objects one hundred times smaller than the smallest object seen by the best microscope. But it had disadvantages. Electrons are easily deflected from their path, so that object being examined must be kept in a vacuum. This means that living tissues cannot be examined. The electron microscope has revealed the existence of very small particles of life – much smaller than bacteria – called viruses. Some of these viruses can cause diseases in man. An example is the poliomyelitis virus – the cause of 'polio'. The development of the microscope has led to a better understanding of the nature of a totally new group of diseases. Thus, as often happens in science, a development in one branch has led to startling discoveries in quite a different branch – medicine.

How living things begin

5.1 What is inside an egg?

In the last chapter you examined the root of a mustard seedling and found that it contained a number of cells. In fact, the bodies of all plants and animals are composed of cells which are not necessarily all alike. Some cells, called sex cells, have special functions to perform when the animal or plant reproduces to make a new individual.

In this chapter we are going to look more closely at sex cells to find out what happens during reproduction.

You will be examining first of all a hen's egg which mostly consists of yolk surrounded by white (albumen).

You are provided with three eggs marked A, B, and C. Egg A has been hard boiled while B and C have been kept warm in an incubator.

Examining eggs A and B

The inside of a hen's egg is difficult to examine but if you look at the hard boiled egg A, first you should be able to see a number of interesting things.

1. Take off the shell carefully.
2. Cut the egg in two lengthwise. Compare your egg with your neighbour's. Is the yolk always in the middle of the white? Is the yolk the same colour all the way through?
3. Now look at egg B. There is a date marked on the top of the egg. Keep the egg this way up and place crumpled paper towelling in a Petri dish or small bowl, both to keep the egg warm and to stop it from turning round.
4. Using the handle of a scalpel, crack the egg across the top and pick off the bits of broken shell until you have made a window as in figure 50. Can you see anything lying on the yolk?
5. Break the egg into a Petri dish in which there is some warm salt solution, if possible without damaging the yolk.
6. Look inside the broken shell and find the air space. Which end of the shell is it situated? Can you see a membrane sticking to the inside of the shell?

1
crack the egg with
the handle of a scalpel

2
using forceps carefully
pick off bits of shell

3
a window has been
made in the shell

Figure 50
How to open an egg.

7. Now examine the white. Is its appearance the same all through? Can you see that at either end there are strands of tougher white matter? These support the yolk so that it can turn round whichever way the egg is turned, like a ship's compass.

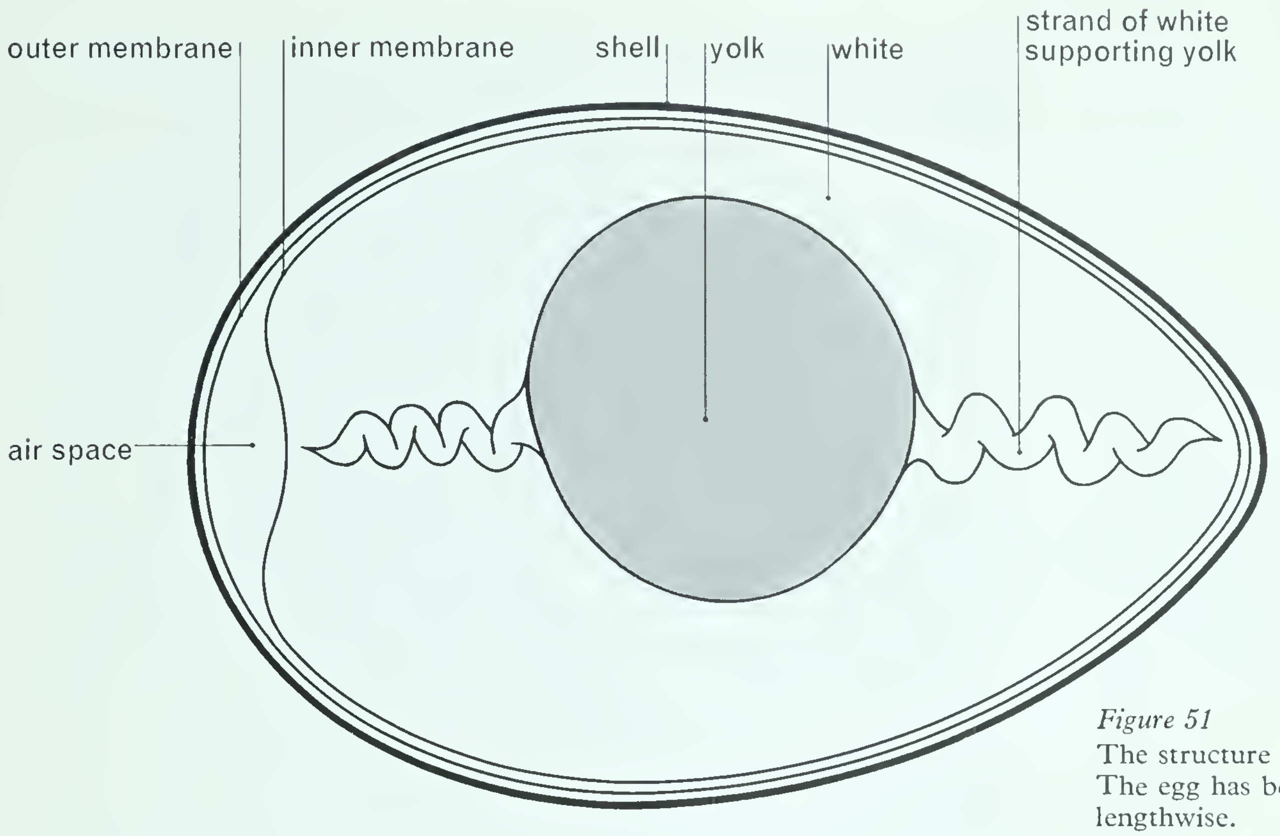


Figure 51
The structure of a hen's egg.
The egg has been cut into two lengthwise.

Look at figure 51 and see if you can make out, on your egg, all the parts labelled in the diagram. Perhaps you can now see why the yolk is not always in the middle of the white.

Examining egg C

If a poultry keeper wants to produce eggs that will hatch into chickens, he must let his hens mate with the cocks. Egg C was laid by a hen which had been mated. Is it different in any way from the two other eggs you have examined?

1. Keeping the egg with the date mark on top, place it on paper towelling and crack it as you did before.
2. Pick off the bits of broken shell. Can you see anything lying on the yolk? (See figure 52.)
3. Now break the egg into a dish in which there is some warm salt solution. If you are lucky you will probably be able to see that there is something lying in a clear fluid on top of the yolk.
4. With a pipette draw up some warm salt solution and drop a little onto the clear part in the middle of the yolk.

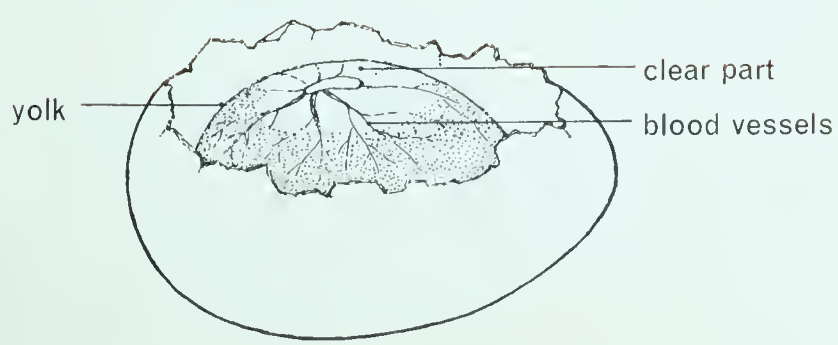


Figure 52
Egg C.
A window has been made in the egg.

5. Under a lens you may be able to see that there is a tiny chick *embryo* with a heart that is beating. You may also be able to see blood vessels extending over the yolk from the embryo.

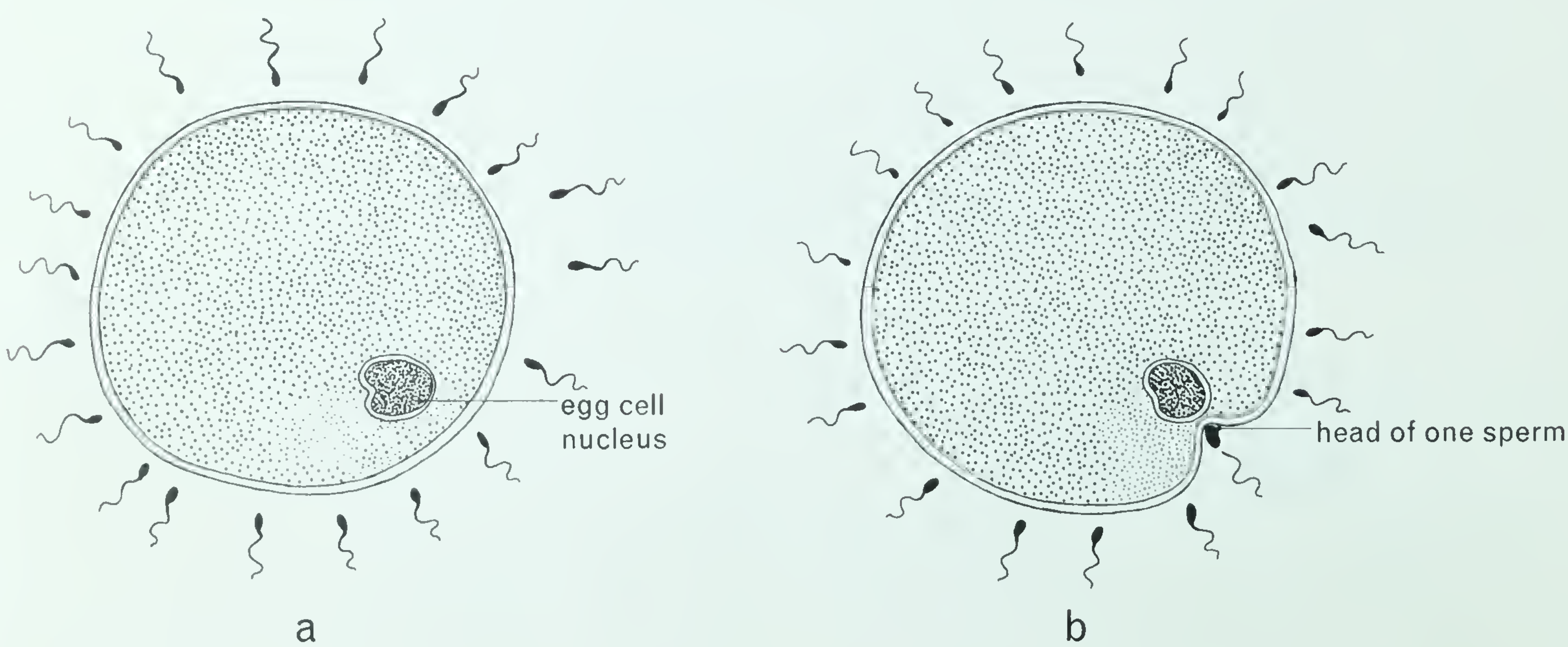
5.2 Finding out how an egg cell starts to grow into an embryo

If we could look at an egg inside a hen which had been mated to a cock, we might be able to see with the aid of a microscope, what happened at the beginning to produce the embryo. Somewhere on the surface of the yolk there is a very tiny speck – a single cell with a nucleus, like one of the cells of the squashed mustard root you examined in Chapter 4. This is the *egg cell.* With still higher magnification we might see a large number of even smaller cells, swimming about near the egg cell each with a tail which it uses for movement (see figure 53*a*). These are called *sperms* and are produced by the cock. In figure 53*b* one of the sperm cells is pushing through the membrane surrounding the egg and eventually joins with the egg nucleus. By this action the egg is *fertilized.*

Once this has happened, the fertilized egg starts to divide – first into two cells, then into four, eight, sixteen and so on until there is a group of cells which is the beginning of the embryo. Figure 54 shows this process of cell division. The example used is the egg of a starfish because the cells are large and easy to study, but the same process takes place in a fertilized hen's egg, except that the cells form a flat circular sheet instead of a ball.

But how does the sperm from a cock reach the egg cell? Look at figure 55 where the cock and hen are mating. The cock mounts the back of the hen and passes fluid containing sperms from his sperm duct under the tail into the egg passage, or oviduct, of the hen. Because the sperms have tails, they are able to swim up the egg passage inside the hen until they reach an egg cell. There fertilization

Figure 53
An egg cell is fertilized.
a. Sperms surround an egg cell.
b. The head of one sperm joins the nucleus of the egg cell.



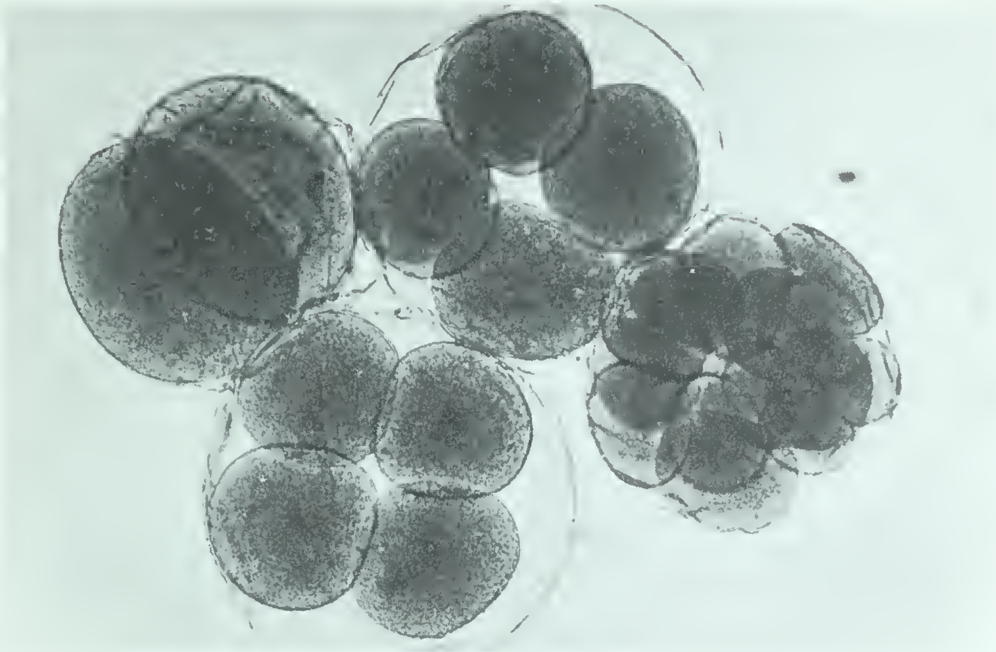


Figure 54
The fertilized egg of a starfish divides. The left hand egg has divided into two cells; the two eggs in the centre have each divided into four cells; and the egg on the right has divided to make a ball of cells. *Frank Lane* (*H. Spencer*).

occurs, and the egg then starts to divide as we have just described. When fertilization of the egg occurs inside the body, it is called *internal fertilization*. The sperms and eggs which take part in the process are known as *gametes*.

This kind of reproduction, in which a new generation is started by the union of the sperm (male gamete) with the egg (female gamete) to form the fertilized egg, is called *sexual reproduction*. This is the way in which most animals reproduce, and most plants as well. We shall be investigating the process in plants later on.

We cannot watch fertilization in a hen because it takes place inside the female but we can observe the process in another animal – the small marine worm *Pomatoceros triqueter*. This lives in a white tube of lime with a keel on top; you can often find it firmly attached to

Figure 55
A cock mating with a hen.
From 'The social order of chickens' by A. M. Guhl, Scientific American, *1956*.

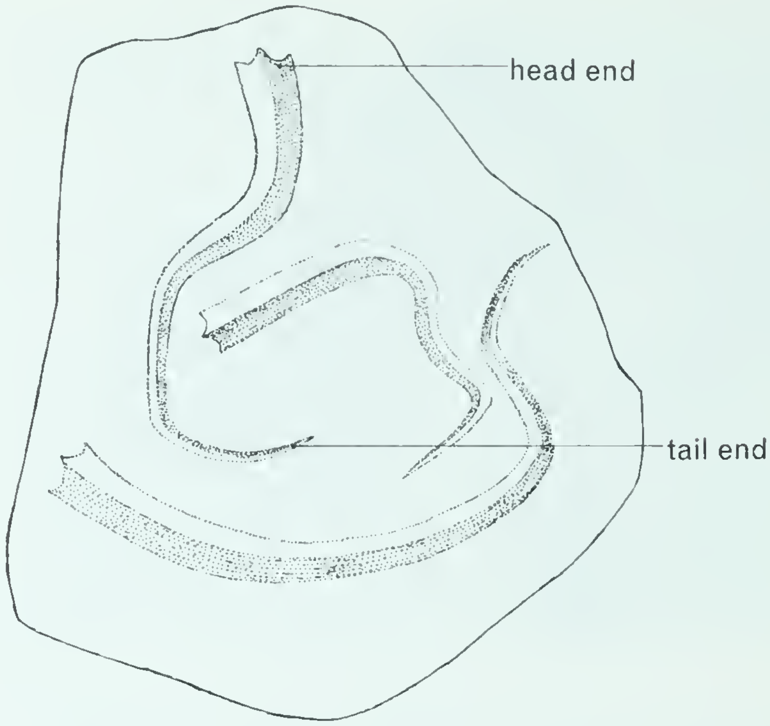
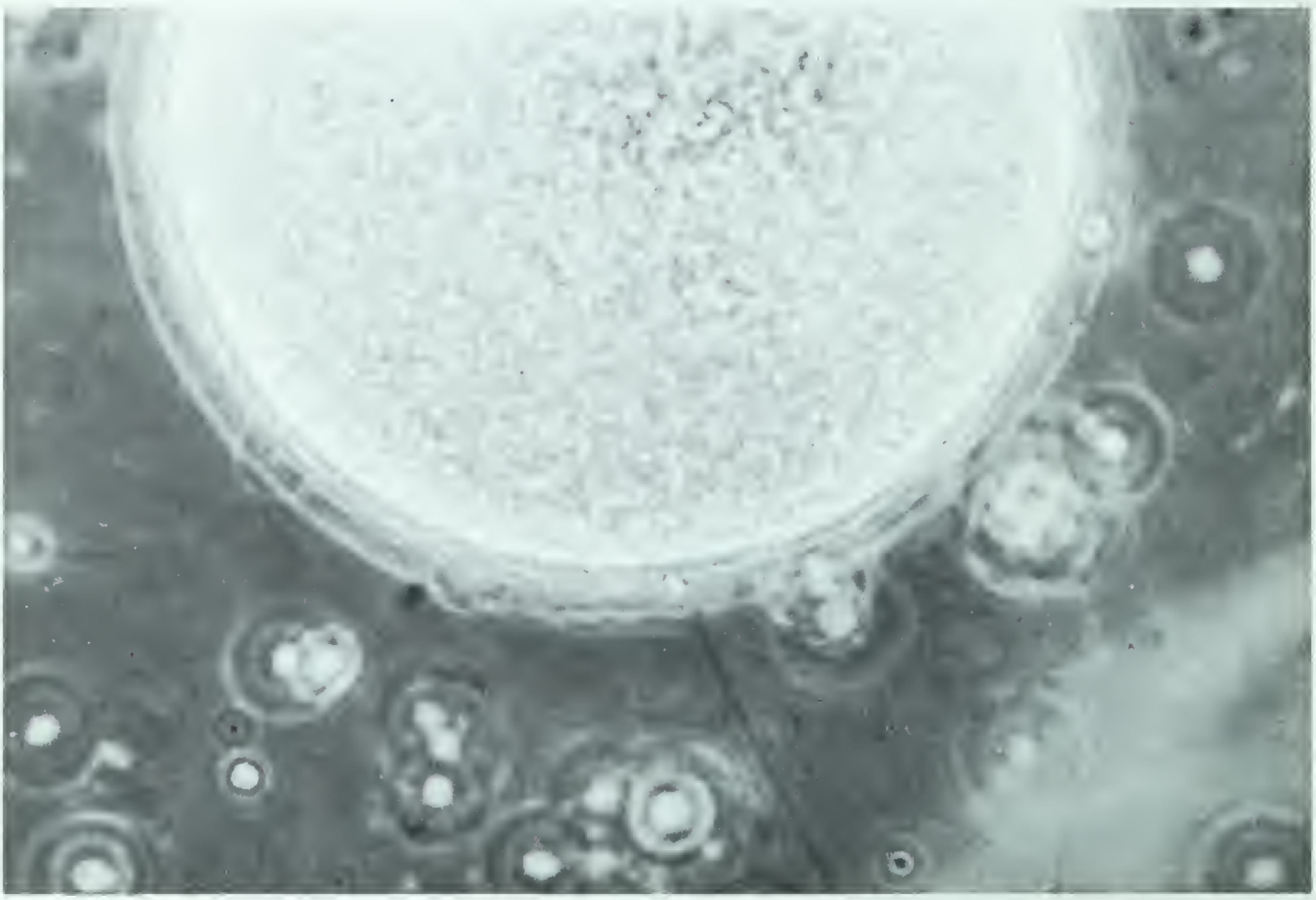


Figure 56
Marine worm, *Pomatoceros triqueter*.
Several tubes attached to a stone, in each of which lives one worm. Note the keel on the tube which comes to a point at the wider (head) end of the tube. The worms live on the shore between tide marks.

Figure 57
A photomicrograph of the egg of *Pomatoceros* (100μ in diameter) surrounded by sperms. The heads of two sperms have just pushed through the membrane surrounding the egg. *Photo by Jack Cohen.*



rocks and pebbles between tide marks (see figure 56). You can quite easily push the worms out of their tubes with a blunt seeker. You can tell the males from the females because their bodies are yellow, while the females are either red or violet in colour. As soon as the worms are removed from their tubes, the males release sperms and the females release eggs. Both eggs and sperms are too small to be seen with the naked eye, but under the microscope you can see them quite distinctly.

1. Look first at the eggs of *Pomatoceros* under the microscope. Can you see that each egg cell has a nucleus?
2. Then pipette a small drop of sea water containing sperms released by the male worm onto the eggs. Can you make out hundreds of sperms swimming about in the water?
3. You will need to watch very carefully to see what happens next. The eggs are much larger than the sperms, so probably you can only see one egg in the field of your microscope. Are the sperms swimming round the egg? One or two sperms may push through the thin membrane (skin) surrounding the egg cell, leaving their tails behind. The head of one sperm joins with the nucleus of the egg, but you may not be able to see this clearly because the head of the sperm is very small. Fertilization of the egg has taken place. You can tell that this has happened because the membrane round the egg starts to swell.

Figure 57 is a photograph of an egg of *Pomatoceros* taken through a microscope. Sperms are swimming round the egg and the heads of two of them have just pushed through the membrane surrounding the egg.
4. After a few minutes look at the fertilized egg again under the microscope. What has happened? Is there still only one cell or has the cell divided to form four or eight cells in a ball like the egg of the starfish? (See figure 54.)

5.21 Different kinds of eggs and sperms

Figure 58 is a photograph of a sperm fertilizing a mouse egg. The egg and sperm are magnified many hundreds of times but you can see that the egg cell is much larger than the sperm. Because the egg has no tail, it cannot move about.

Figure 59 shows the eggs of a number of different animals drawn about natural size. Some can be seen quite easily with the naked eye. For instance a hen's egg is relatively large and weighs about 2 oz. The eggs of some birds are even larger – that of an ostrich is 7 inches long and 6 inches in diameter. Frog and fish eggs can be quite large too. All these contain a lot of yolk which nourishes the growing embryo. But the eggs of most mammals are microscopic, like that of a mouse. This is strange when you think how large mammals can grow; but you may be able to find an explanation later on.

Sperm cells, on the other hand, are very small indeed – far too small to be seen without a microscope. Those in figure 59 are magnified 430 times. They vary in shape but their tails enable them to move about provided there is some kind of liquid in which to swim. Unlike the egg, they have practically no food store and thus cannot live for long. Figure 60 shows the sperms of a boar. Notice the head of each sperm and its long tail.

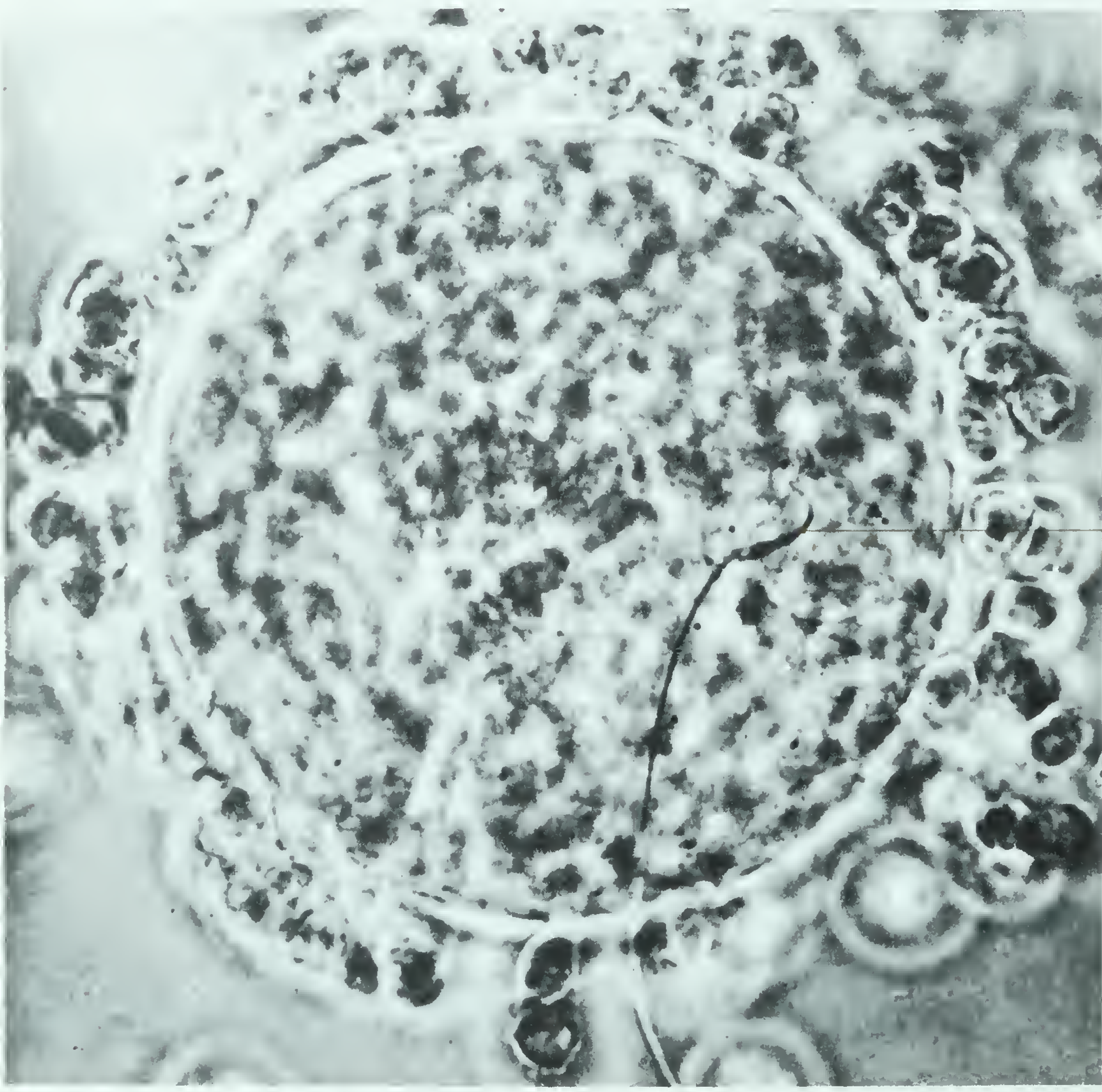
5.22 The hen's egg starts to develop

After the hen's egg has been fertilized inside the egg passage of the hen, it begins to divide into a number of cells just like the egg of *Pomatoceros* which you have been looking at.

As the egg passes down the oviduct before being laid, it divides all the time to form the beginning of an embryo and the walls of the oviduct produce the white (albumen) which surrounds the yolk. A shell is added just before the egg is laid, but by this time the embryo is already twenty hours old.

While the egg has been inside the hen, it has remained at a temperature of 38°C. So if we want to allow the embryo to go on growing, we must put the newly laid egg into an incubator at the

Figure 58
A sperm fertilizes a mouse egg. The head of the sperm has pushed through the membrane surrounding the egg and will soon join the nucleus. The tail of the sperm is still outside the egg. *By kind permission of Dr C. R Austin.*



right temperature. The eggs B and C which you examined in section 5.11 were incubated, but because B was laid by a hen without a cock the egg cell was not fertilized and we say it was *infertile*. Egg C, on the other hand, was the result of a cock mating with a hen, and the fertilized egg grew into an embryo chick with a distinct head and tail, and a heart which pumped blood through blood vessels covering the yolk. The yolk provides food for the developing chick

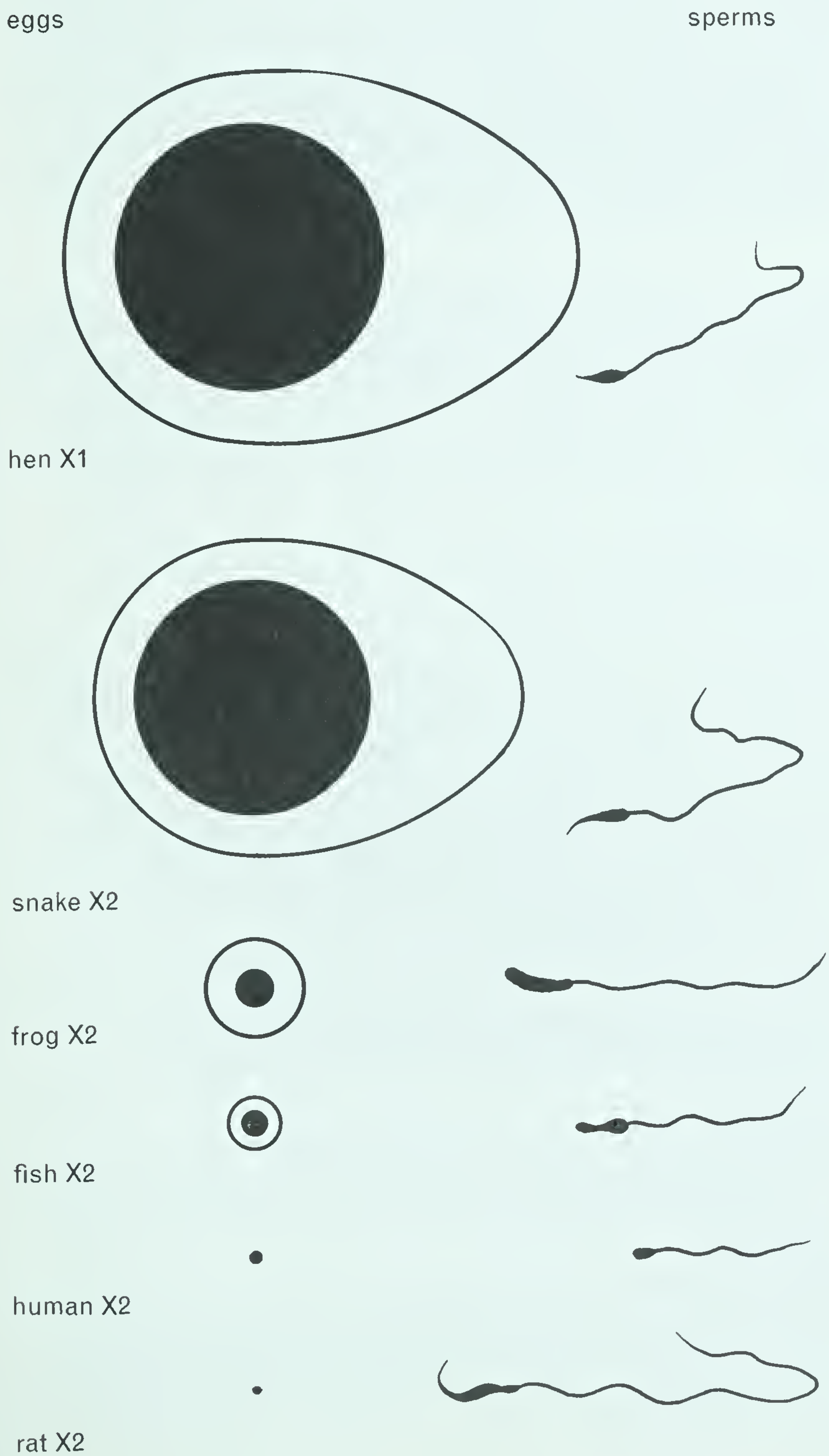


Figure 59
Eggs and sperms of different animals.
The sizes of the eggs are given. Note that the sperms are all magnified approx. 500 times.
In the hen, snake, frog, and fish the egg cells are surrounded by other materials such as white (albumen) and a shell.

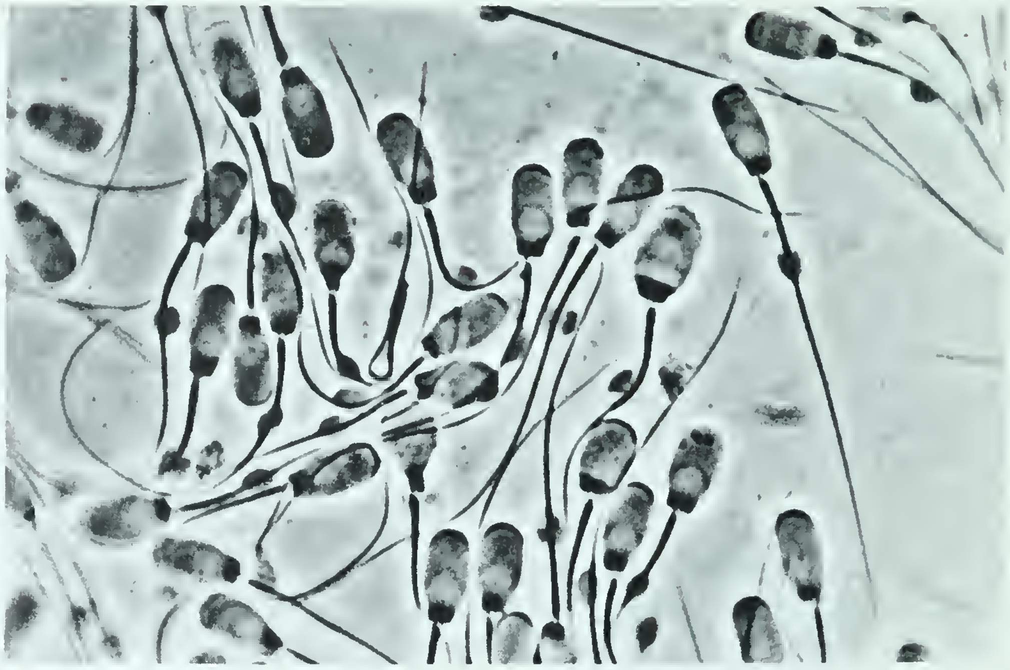


Figure 60
Sperms of a boar × 1,200.
Like the sperm cell of the mouse, in figure 58, these sperms each have a head and a tail. *Photo by Dr T. Mann.*

while it is still in the egg. The white protects the embryo, cushioning it against vibrations and movements when the hen turns her eggs in the nest. The membranes and shell also protect the chick but allow air to pass into and out of the egg so that the embryo can breathe. The air space at the end of the egg provides a reservoir of air.

5.3 Incubating eggs

In section 5.11 we found that a fertile egg contains a living embryo. That is to say, each one contains a living chick which needs to breathe, feed, and to be kept warm. In addition it must also be kept moist. A hen sitting on her own eggs keeps them warm (at a temperature of about 38°C) and turns them several times a day. The moisture from her body keeps the eggs in a damp atmosphere.

If you look at the diagram of an incubator in figure 61 you will notice that it is designed to copy the conditions which the hen provides for hatching her eggs.

From the observations which you made in section 5.11 on the structure of the egg, can you answer these questions:

a. Why should the eggs be turned at least twice a day?

b. Why should there be a current of fresh air passing through the incubator?

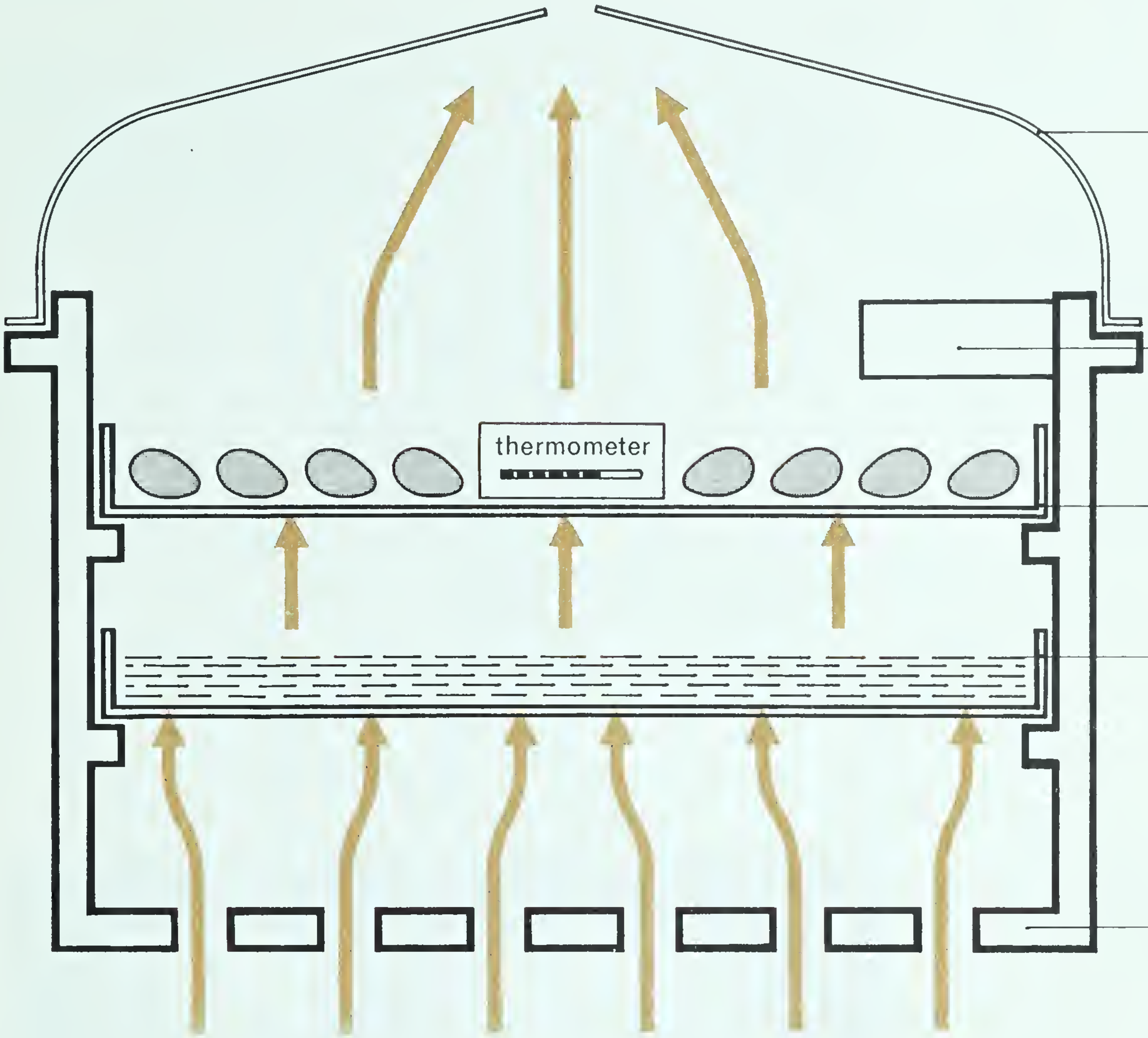
c. Why do the eggs need to be in a moist atmosphere?

d. When you take an egg from the incubator to examine the embryo, why should you be careful to hold it the same way up as it was in the egg tray?

e. Why is the incubator kept at 38°C?

f. Why should you wrap the egg in paper tissue or cotton wool before transferring it to the place where it is going to be examined?

Here are some rules which you should follow when looking after eggs in an incubator:



1. Each egg should be marked, on one side, with the date on which it is put into the incubator.
2. Every morning and afternoon the eggs should be turned by rolling them over sideways with the tips of the fingers. If the marked side was on top, they should be rolled over so that it is now underneath. Wash your hands before turning the eggs.
3. Every morning and afternoon check the temperature. (It should be 38°C.)
4. Twice each week, distilled water should be added to the moisture tray to bring it up to the right level.

Figure 61
Section through an egg incubator. The arrows show the flow of air.

5.4 The chick embryo grows

Let us incubate some fertile hens' eggs and find out how quickly the embryos grow. To study the rate of growth we can measure the length of the embryo at intervals until it is 10 days old. You can also see how the embryo develops new structures as it gets bigger.

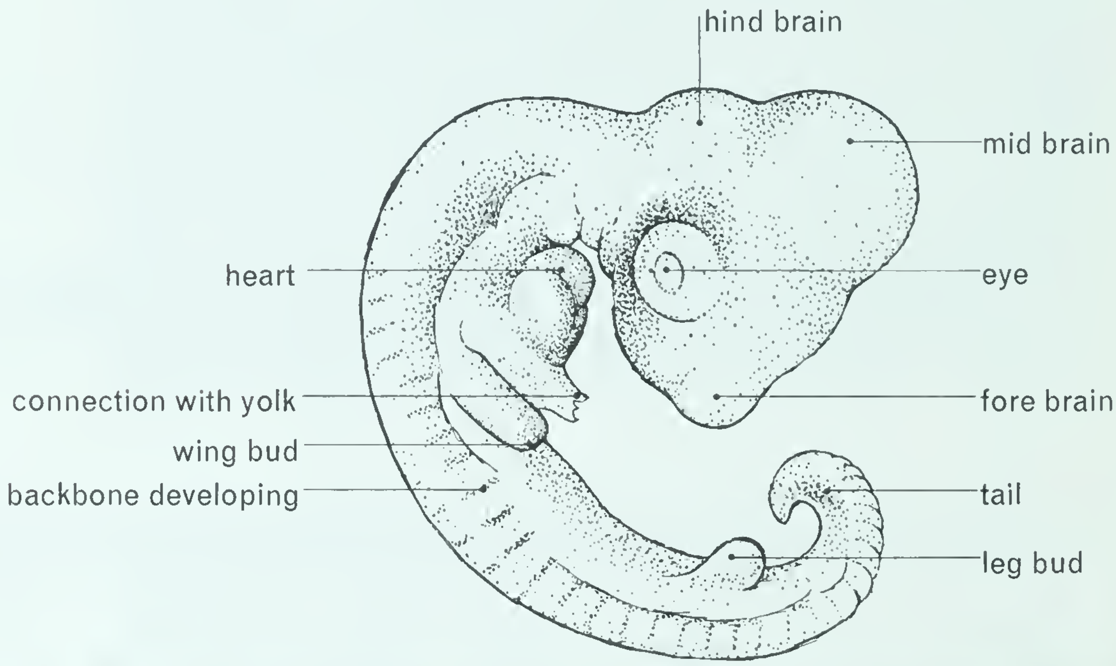


Figure 62
3½ day old chick embryo × 6.

Figure 63
3½ day old chick embryo × 9. The wing and leg buds, and the eye are developing. The heart is still outside the body. Compare the photograph with the drawing in figure 62. *Photo by B. Bracegirdle.*

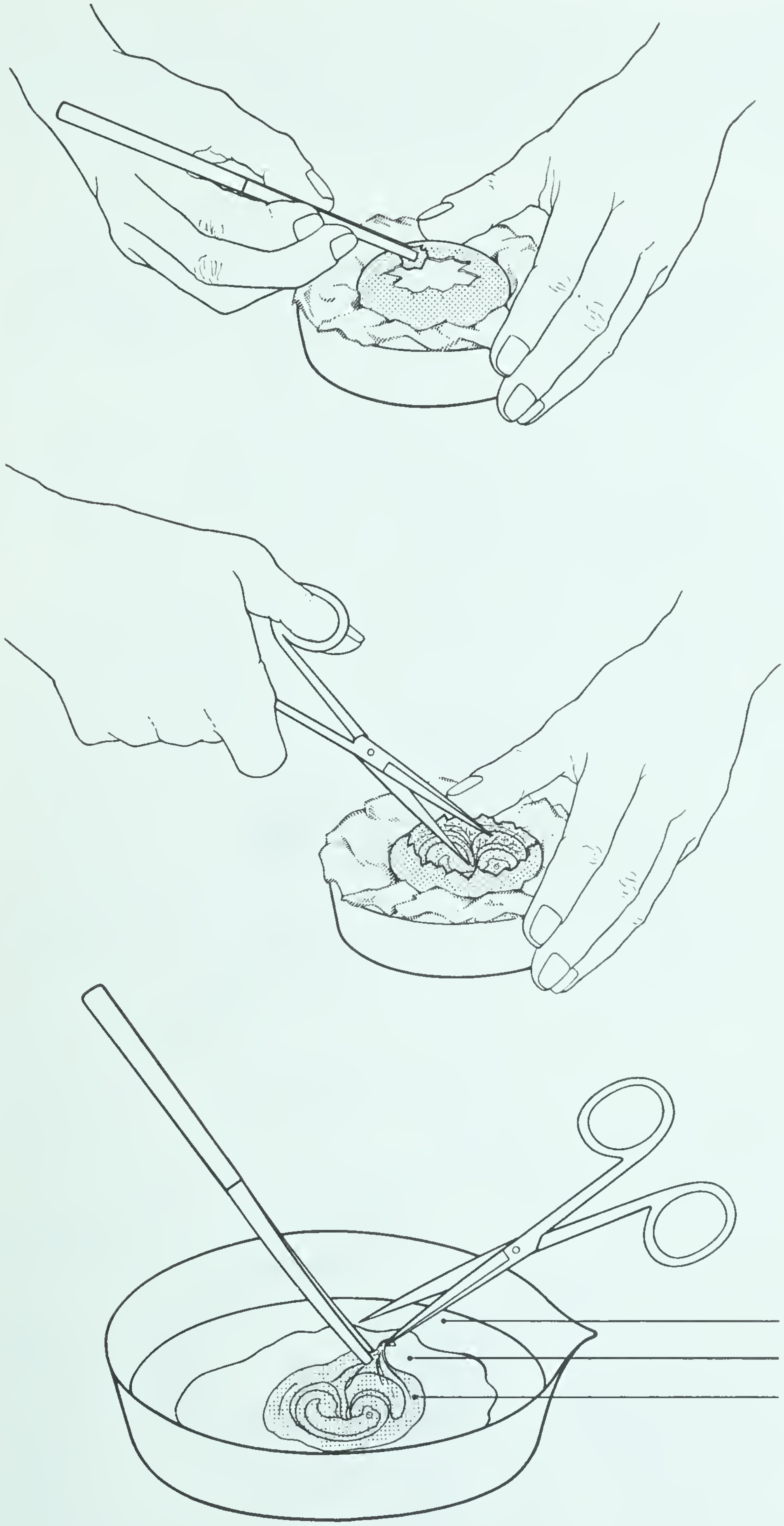


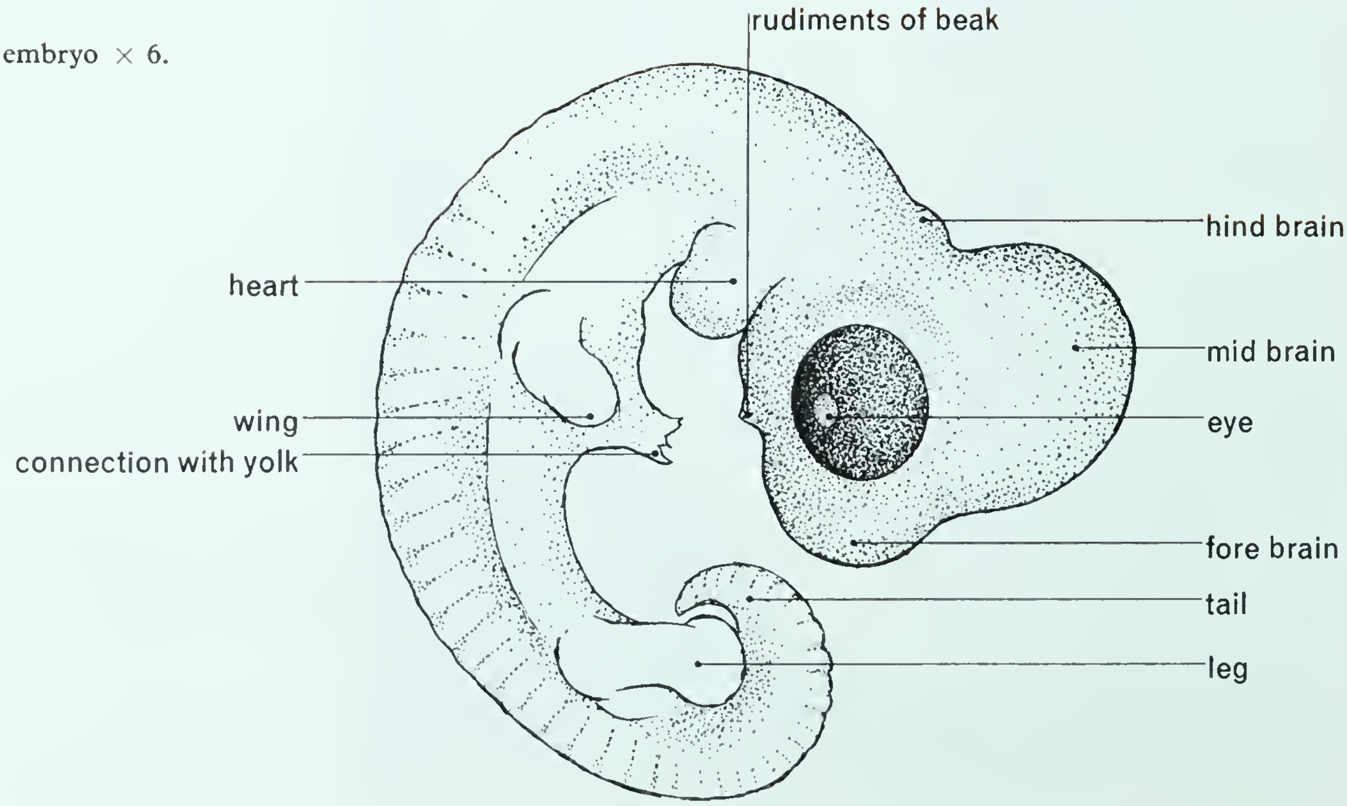
Figure 64
Preparing to look at a 5 day old chick embryo.

Five day embryo (figure 65)

Figures 62 and 63 show a drawing and photograph of a chick embryo when it is $3\frac{1}{2}$ days old. At this stage it is too small to remove easily from the yolk and white of the egg. Try separating the embryo when it is 5 days old.

1. Take the egg out of the incubator and, keeping it the same way up, put it into an evaporating basin lined with paper towelling.
2. With the handle of a scalpel, gently crack the top of the egg and, using forceps, pick off the broken shell as in figure 64, stage 1.
3. With a pair of scissors cut round the membrane inside the shell to expose the inside of the egg (see figure 64, stage 2).
4. By this time the yolk will have become rather watery and the embryo will be enclosed completely in another skin (the amnion).
5. With a hand lens, look at one of the large blood vessels spreading over the yolk. Can you see the blood moving along inside?
6. Remove the paper towelling and put some warm salt solution into a Petri dish. Break the egg into the dish.
7. Using forceps and scissors, cut away the amnion and expose the embryo (see figure 64, stage 3). What is inside the amnion besides the chick embryo?
8. Clean the embryo as much as possible by removing the membranes with forceps and scissors, being careful not to cut the embryo itself. You will probably need to wash the embryo in several rinsings of water to clear it of yolk and white.
9. You should now be able to make out the various structures more clearly (see figure 65). Compare the size of the eye with the size of the head. Is the eye larger than that of the $3\frac{1}{2}$ day old embryo in figures 62 and 63? Can you see that the eye is covered with black

Figure 65
5 day old chick embryo × 6.



pigment, except for the central part which is the lens? The wing and leg buds are just visible in the 3½ day old embryo (see figures 62 and 63). Have they grown larger? Can you make out the beginning of the beak? Can you see the heart beating?

Measuring the embryo

Since the embryo is curled up, it is difficult to measure its length unless you first uncurl it. Get your partner to hold the embryo with two seekers as in figure 66 which shows a 3½ day old embryo.

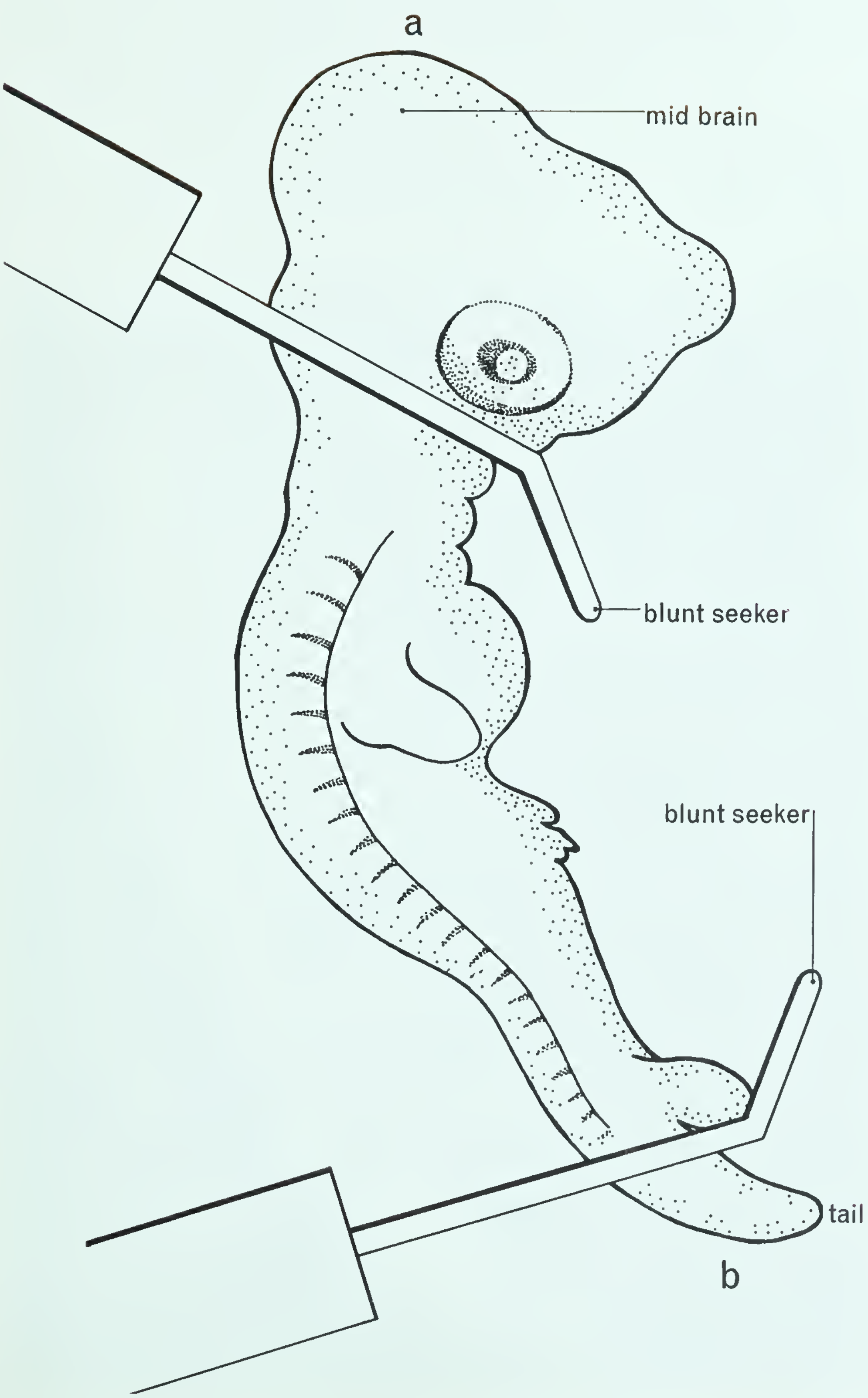


Figure 66
Measuring a 3½ day old chick embryo.

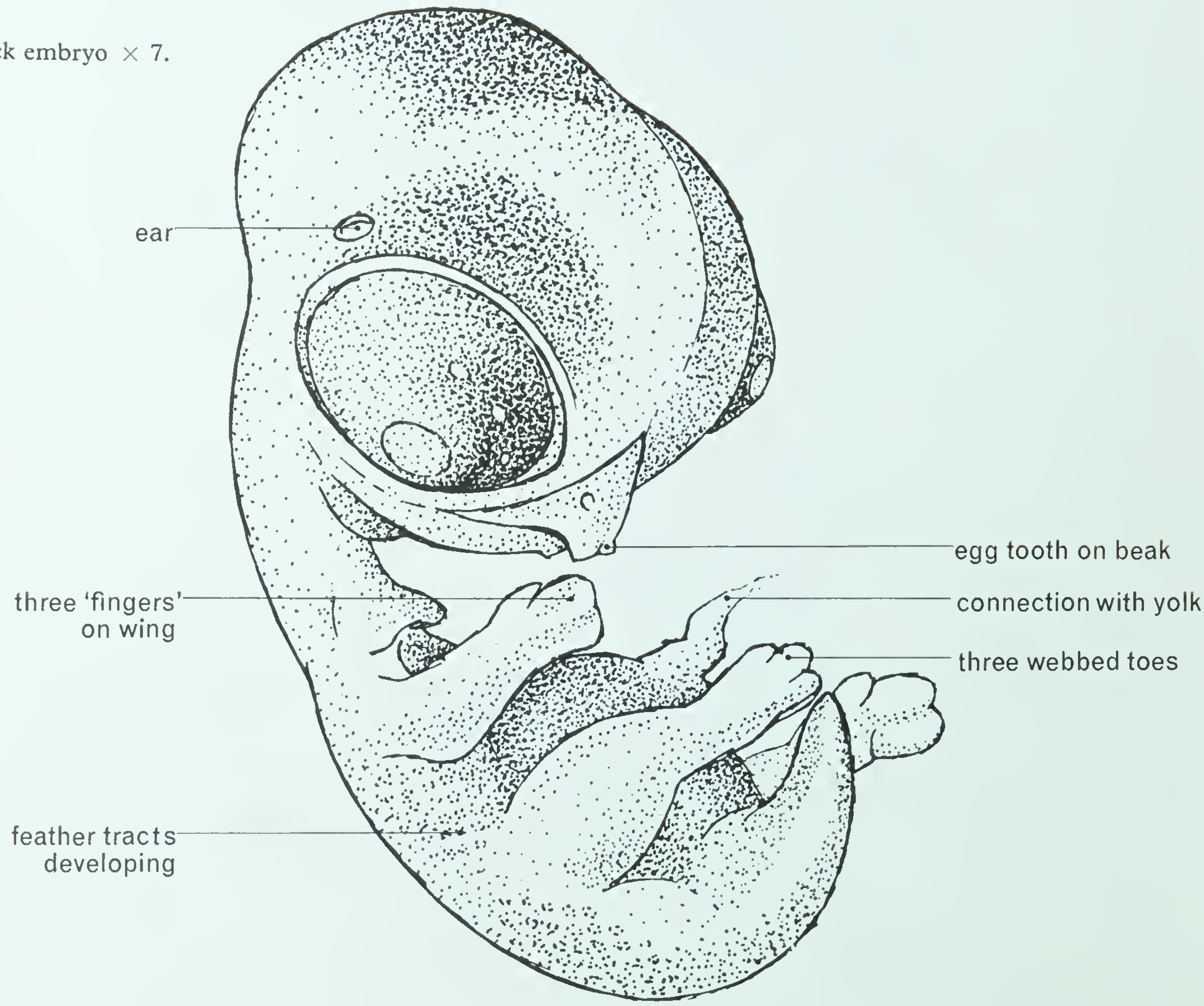
1. Make a table, like the one below, for your records every time you make a measurement. The table has been completed for the $3\frac{1}{2}$ day old embryo.

2. Measure the 5 day old embryo from point A (mid-brain) to point B (the tail) (see figure 66) and record its length, in millimetres, in your table adding your own notes in the last column of any particular things you have noticed.

Date	Age of embryo	Length of embryo	Notes
18.2.65	$3\frac{1}{2}$ days	12 mm	Head very large. Eye visible. Heart, outside body, can be seen beating. Wing and leg bones visible.
?	?	?	?
?	?	?	?
?	?	?	?

Table of measurements

Figure 67
7 day old chick embryo × 7.



Seven day embryo (figures 67 and 68)

1. After chipping away the surface of the egg as you did before, break it into a warm Petri dish and, with blunt seekers, push the embryo to the edge of the yolk.

2. The embryo will still be attached to the yolk by blood vessels, so you will have to cut these with scissors in order to free the chick completely. The chick dies almost immediately the egg is broken so it will not feel anything now. The embryo is still curled up. Can you make out the structures labelled in figure 67? The small white dot which you may be able to see on the tip of the beak is the egg tooth by means of which the chick breaks through the shell when it is ready to hatch. Is the eye even larger now by comparison with the size of the head? The tail, wings, and legs are now clearly visible. Can you see the three webbed toes?

3. With the help of your partner straighten the embryo out as you did before and measure its length from point A (the mid-brain) to point B (the tail) (see figure 66), recording this in your table, adding notes in the last column of anything interesting you have noticed.

Figure 68
7 day old chick embryo × 6.
The eye is now very large, the ear shows as a hole behind the eye and the egg tooth is developing on the beak. The wing buds show three 'fingers' and the feet three webbed toes. Compare the photograph with the drawing in figure 67. *Photo by B. Bracegirdle.*

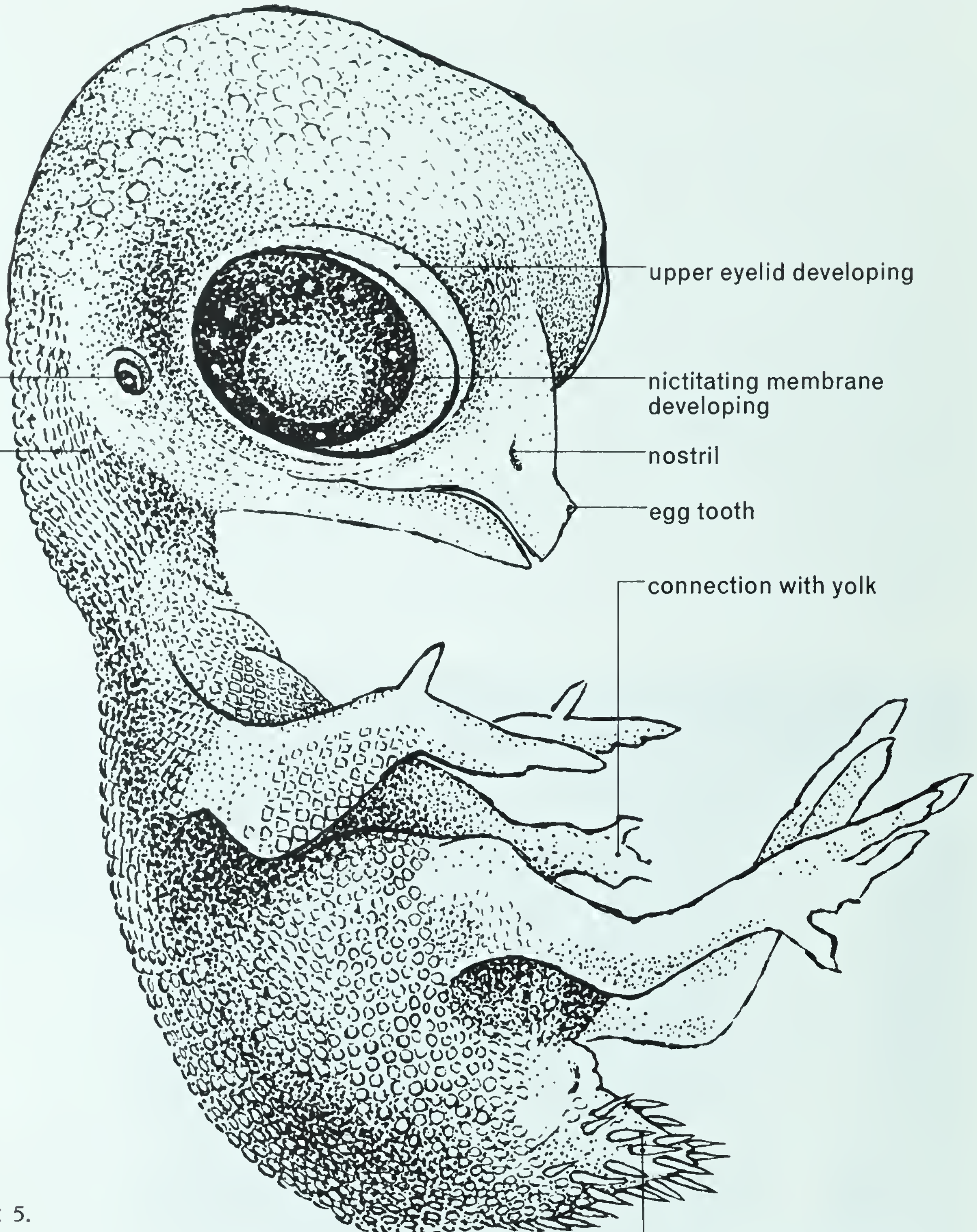


Figure 69
10 day old chick embryo × 5.

Ten day embryo (*figures 69 and 70*)

1. Break the egg into a Petri dish.

2. Separate it from the yolk as you did before. For the first time, the embryo looks quite bird-like. The beak is now well formed and the toes are distinct. What other new structures do you see?

3. Look at the eye and see if you can make out the parts labelled in figure 69. Most birds have a *nictitating membrane* over each eye. It is really a third eyelid which protects the eye of the bird from dust and the glare of the sun when it is in flight. Look at your partner's eye. Right in the corner, can you see a small piece of pink skin? This is all that remains of the nictitating membrane in human beings.

4. Measure the embryo, as you did before, from point A to point B (see figure 66) and record its length on your table. Make notes of whatever interesting things you may have observed.

Figure 70
10 day old chick embryo × 3·5. The eye is developing an eyelid and nictitating membrane. Both wings and legs are larger and there are now five toes. Feathers are forming on the tail and the embryo looks more bird-like. Compare this photograph with the drawing in figure 69. *Photo by B. Bracegirdle.*

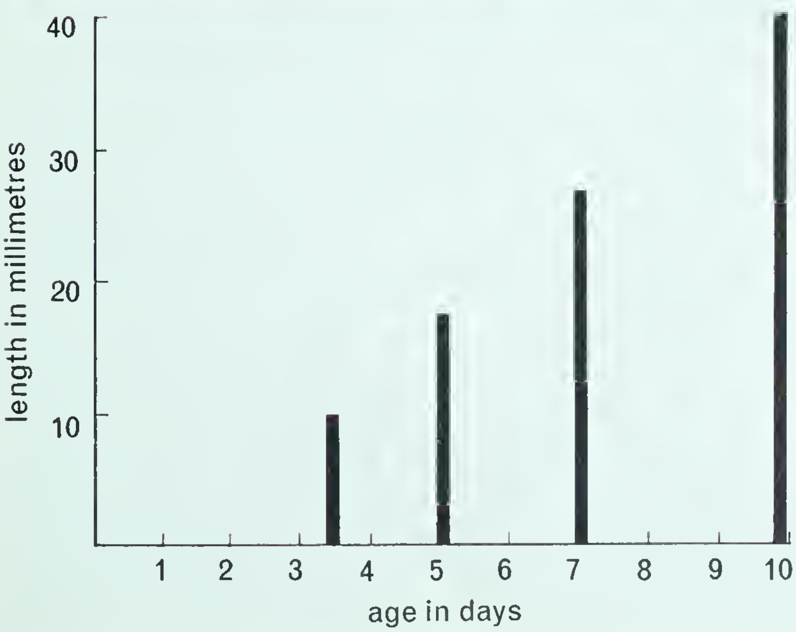


Figure 71
Bar graph showing the growth in length of a chick embryo from $3\frac{1}{2}$ days old to 10 days old.

From the measurement of the $3\frac{1}{2}$ day embryo and your own records, you could construct a bar graph of the increase in length of the embryo, like that in figure 71. Join the bars with a line, running through the middle of the top of each bar. If it is (*a*) straight or (*b*) curved, what does your graph tell you about the growth in length of the embryo chick from the $3\frac{1}{2}$ day stage to the 10 day stage?

5.41 The chick hatches

If you have any eggs over, you could go on incubating them. They

Figure 72
A chicken hatches from an egg.

a. The membranes inside the egg are split and the shell cracked.

b. The beak of the chicken enlarges the hole in the shell.

c. The damp chick is still curled up but is nearly free.

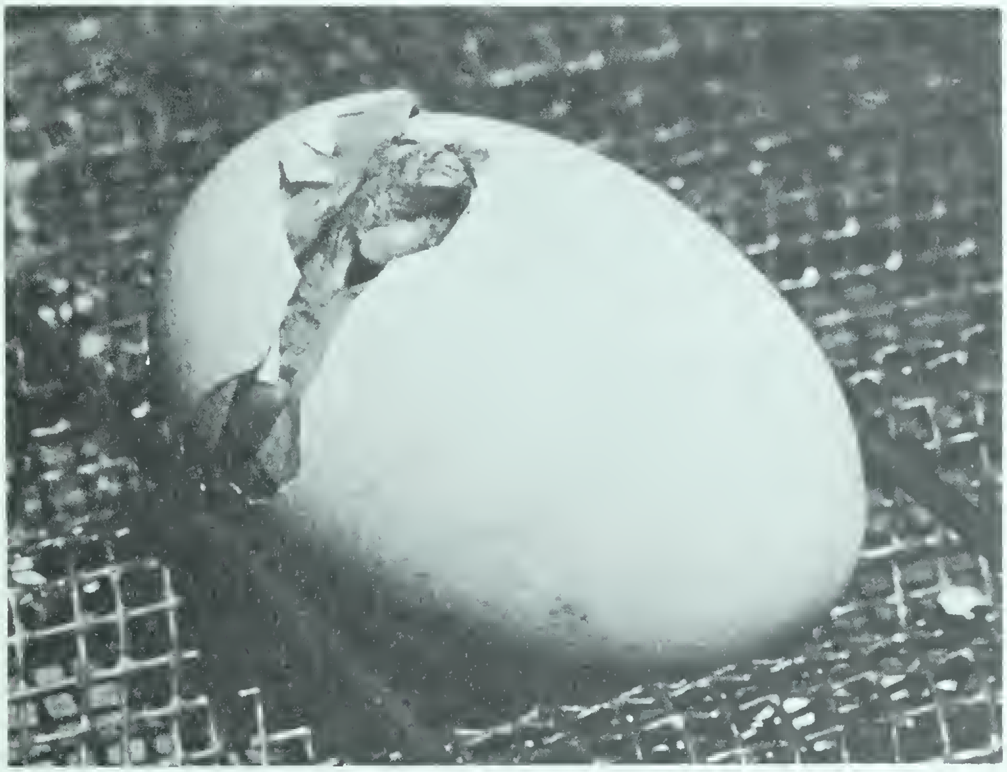
d. The chick has hatched and its feathers are now dry and fluffy.
Photos by Pictorial Press.

a

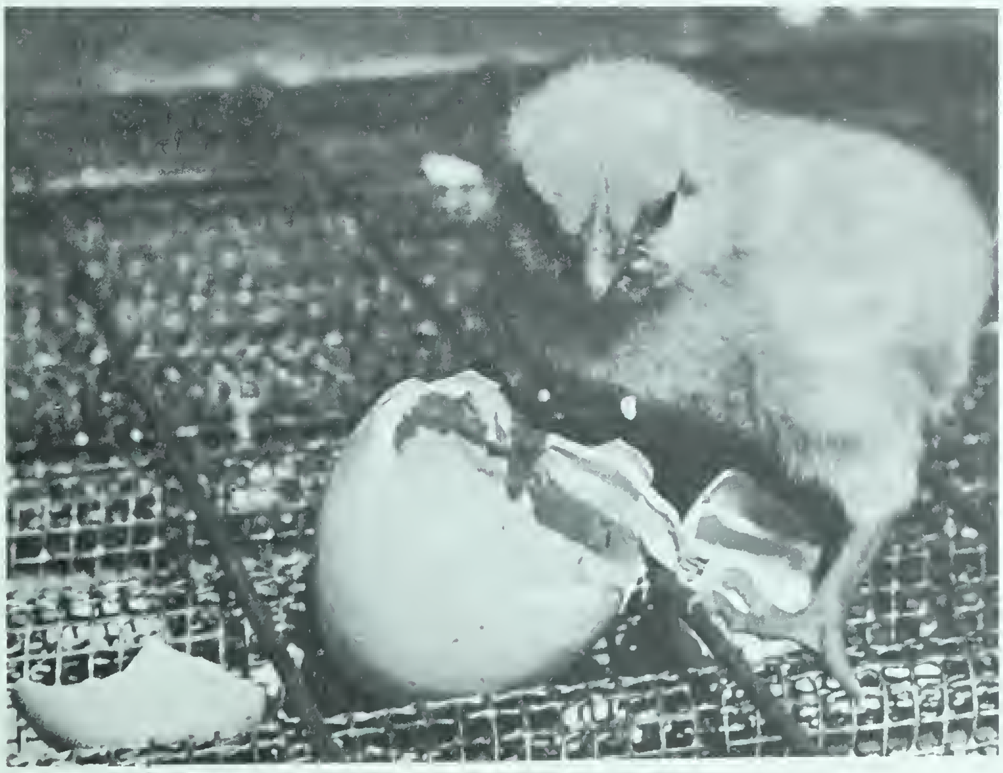
c

should start to hatch on the twenty-first day and the actual process of hatching is most interesting to watch. Movements of the chick within the shell cause the head to be jerked forward and the beak upwards. The egg tooth on the beak is now quite large and these movements split the membranes inside the shell and finally crack the shell itself (see figure 72*a*). The chick kicks with its legs and the beak enlarges the hole in the shell (see figure 72*b*). When it first appears the chick looks rather shaggy and damp but its downy feathers soon dry and it is now a fluffy chicken (see figure 72*c* and *d*).

It is amazing to think that the single-celled embryo, with which



b



d

we started the story, can develop, in the space of just 21 days, into a day-old chick covered with feathers and able to peck its own food.

Summary

Sexual reproduction involves two parents – the male to produce sperms, one of which unites with an egg cell produced by the female parent. The result of such a union is a fertilized egg. The egg can only develop if it has been fertilized.

Reproduction and development in animals and man

6.1 Mating and fertilization in animals living in water

We have seen that in animals such as birds, fertilization is internal – the eggs are fertilized by the sperms inside the body of the female. But in the marine worm, *Pomatoceros*, the sperms released by the male swam in the sea water to reach the eggs released by the female. When fertilization takes place outside the body in this way, the process is called *external fertilization.*

The eggs of many species of freshwater and marine animals are fertilized externally and the sperms swim, by means of their tails, to reach the eggs.

Herrings live in shoals and at certain times of the year, the males and females congregate in huge numbers on the sea bed. As soon as the eggs are laid they sink to the bottom and the male herrings release sperms into the water around them. The sperms swim in the sea and eventually some will find eggs which they fertilize. But, as you can imagine, this is a very wasteful process. One female herring lays as many as 10,000 eggs in a year while the male produces many millions of sperms. Some eggs may not be fertilized and therefore will not develop, while millions of sperms will also die. Thus for aquatic animals, external fertilization is a risky process involving the production of large numbers of eggs and sperms in order to make sure that at least a few eggs will be fertilized.

We cannot watch the process of fertilization in a fish living in the sea, but some of the easiest animals to study are frogs or toads. During spring they leave their winter quarters – under vegetation or in damp ditches – and make their way to ponds and slow-flowing streams. They may have to travel overland for a mile or more to find water. The males often get there first, and await the arrival of the females. As soon as a female appears, a male will get onto her back and hold her firmly with his front legs around her armpits as in figure 73.

Soon the female will start to lay eggs, and as the eggs are laid the male pours sperms over them in the water. Of course we cannot see the sperms because they are far too small, but each has a long tail (see figure 53) and swims in the water like a tadpole to reach the egg. Several hundred eggs may be laid by one frog, but not all will develop into tadpoles, for some may not be fertilized.

Figure 73
Frogs mating. The male common frog, *Rana temporaria*, is as large as the female. When mating, he clasps her round the armpits.
Photo by H. V. Lacey.

6.11 The African clawed toad

Our native frogs and toads only reproduce in springtime. If we wish to study reproduction at other times of the year we can make use of the African clawed toad, *Xenopus laevis* (see figures 74 and 75). As their name suggests, these animals come from Africa and are mostly found in the Cape Province in the south, but also occur in many parts of East Africa.

A large tank or an old sink is the best container in which to keep the toads. In winter time they should remain indoors because they prefer a temperature of about 22°C, although they will live quite happily in water which ranges in temperature from 10°C to 28°C. The toads can leap out of a tank quite easily, so you must use a cover which fits securely over the tank.

They should be fed twice a week and since they are meat eaters (carnivores) they can be offered scraps of raw meat, liver, and even live earthworms. Any uneaten food should be removed from the tank, otherwise it may foul the water. It is best to change the water the day after feeding. The stale water can be siphoned out of the tank and fresh water added. Tap water can be used if it has been allowed to stand for a day or so. This is because it often contains traces of chlorine which is poisonous to animals. The chlorine gradually disappears if the water is allowed to stand.

Figure 74
Female African clawed toad, *Xenopus laevis*.
Notice the 'stitch' marks along each side of the body and round the eyes which are on the top of the head. Also the small front legs with four pointed fingers and the large back legs with five, strongly webbed toes. *Photo by Alan Gentle.*

6.12 Finding out about the habits of the African clawed toad

When fully grown the female toads are always much larger than the males – often as much as four times as big.

If you don't make any sudden movement or shake the tank, the toads will lie quite still on the bottom or at the surface of the water, so that you can watch them.

1. Draw one of the toads in your notebook. What do you notice about its back legs and feet, the shape of its head, and the position of its eyes?
2. Watch the toads swimming about in the tank. How do they use their back legs? Drop a small piece of raw liver in front of one of them. How do they feed? Do they use their front legs at all for grasping the food? How do they convey the food to their mouths – do they swallow it whole or tear pieces off?
3. Try dropping food at different distances from a toad to discover how they find their prey. How far away can they see the food, or do they detect it in some other manner? You will have to be careful when you feed *Xenopus*. Any sudden movements, as we have said, will cause them to swim about wildly in the tank and it takes some time for them to settle down again.
4. Make a list of all the interesting things you observe. The African clawed toad never leaves the water, so from your notes pick out those characteristics which you think show that the animal is aquatic. Can you suggest any reasons why it has a rather small, pointed head and flat body?

When translated, the scientific names of the African clawed toad, *Xenopus laevis*, (Greek, *xenos* = strange; *pous* = foot. Latin, *laevis* = smooth) give a clue to the curious shape of their back feet and to their very smooth and slippery bodies.

6.13 Comparing the African clawed toad with the common frog or the common toad

If you have not got a living frog or toad to look at, find a picture of one.

1. Compare the general shape of the body in *Xenopus* and the common frog or toad. How are they different?
2. Compare the size of the back feet. What other differences do you notice in the back feet?

The large web between the toes of *Xenopus* makes it an extremely fast and powerful swimmer. The claws are too soft to hurt anyone, but when the toad moults, they help to tear off the old skin.

If you keep your animals in a white sink they will go quite pale in colour. This ability to change colour is possessed by many kinds

Figure 75
Male African clawed toad, *Xenopus laevis*.
The male is much smaller than the female but the general shape is the same in both sexes. *Photo by Alan Gentle.*

of frogs and toads. You could try putting them into a dark tank and see what happens and how long it takes them to change colour. Can you think what use it is to frogs and toads to be able to change colour in this way?

Our native frogs and toads are ideal for the study of mating, egg laying, and development of the tadpoles if they are available. Details of their life history have not been given, since you can easily find a good account in almost any natural history book. The stages in development of *Xenopus*, however, will be unfamiliar; thus these are described in some detail in the following sections.

6.14 Mating and egg-laying in the African clawed toad

African clawed toads will not usually mate and lay eggs in the laboratory of their own accord. But we can encourage them to do so by injecting into both a male and a female toad a substance which does not harm them, but which starts off the mating process. After they have each received the injection they are put into a small tank of water kept at 22°C.

1. Look at a pair of toads which have been injected. Are they mating? Is the male holding the female in the same way as the male common frog in figure 73?
2. The female toad will soon start to lay eggs. Watch carefully as she does this. She will continue to lay for several hours. Under natural conditions a female will lay as many as 15,000 eggs, but in a small tank in the laboratory she may only produce a hundred or so. If possible make a note of how long egg laying takes. Are the eggs different in size from those of the common frog? Is there the same amount of jelly surrounding the egg? (See figure 59.)

6.15 Examining the eggs of the African clawed toad

1. With a wide pipette, draw up one of the eggs, which the female has just laid, and place it in a watch-glass.
2. Pipette a drop of water from the tank onto the egg.
3. Place the watch-glass under a binocular dissecting microscope and draw what you see. Does this egg look like the egg of the starfish? (See figure 54.)
4. When you have finished, replace the egg in the tank.
5. As soon as the female has finished laying, the toads should be removed to the big tank once more, otherwise they may eat the eggs.
6. Next day take an egg out as you did before and look at it under a microscope. Has it changed at all? If you see any change, draw the egg again and replace it in the tank. What is happening to the egg? Did your first drawing look like the egg of *Pomatoceros* a few minutes after the egg had been fertilized?

Figure 76 stage *1*, shows an egg of *Xenopus* before it has divided, while in stages *2* and *3* it is starting to divide into a ball of cells like the egg of *Pomatoceros* which you examined in section 5.2.

An egg which starts to divide in this way, has been fertilized by a sperm from the male toad as the egg was being laid. If the egg you have just examined has not divided, this may give you a clue as to the reason.

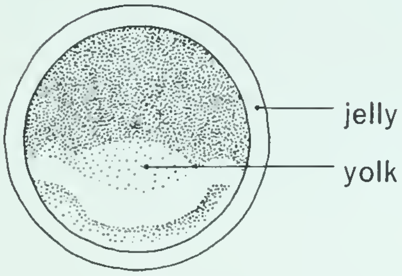
Look again at figure 76 and compare it with your drawings.

6.2 The eggs hatch into tadpoles

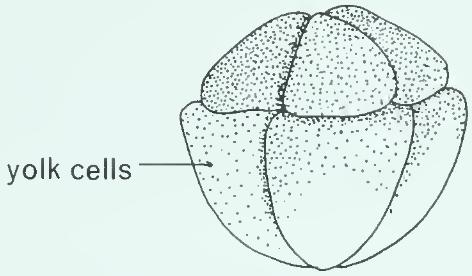
If you are able to look at the eggs every day, you may notice that after about two days the inside of the egg seems to change shape and become longer. The young (embryo) tadpole is now visible and by the third day it may be ready to hatch, and you can watch how tadpoles are trying to struggle out of the jelly.

6.21 Looking after the tadpoles

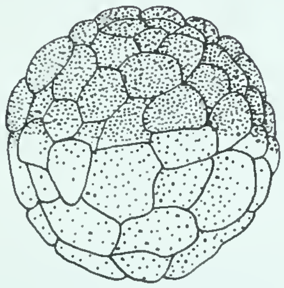
Very soon after they hatch the tadpoles will start clinging to the sides of the aquarium hanging tail downwards. At this stage they have tiny frilled gills on either side of the head and breathe like a



1
An egg which is about $1\frac{1}{2}$ hours old



2
An egg which is about $2\frac{1}{2}$ hours old has divided into eight cells (only 6 cells can be seen)



3
An egg which is about $3\frac{1}{2}$ hours old has divided into a ball of cells
The heavier cells which form the yolk, lie underneath the darker cells which are the beginning of the embryo

Figure 76
A fertilized egg of *Xenopus* divides.

fish, taking in the oxygen dissolved in the water by means of these gills.

Some of the eggs in the aquarium may never hatch. You may already have discovered the reason for this in section 6.15. If these were left in the water they would decompose, the water would smell, and the young tadpoles would die. Instead of removing the eggs from stale water it is easier to take the tadpoles out and place them in a fresh tank of water. This should be prepared beforehand ready to receive the tadpoles – let the water stand for at least twenty-four hours and by means of an aquarium heater and thermostat keep it at 22°C to 23°C.

For the first two or three days the tadpoles cannot feed because they have no mouths but there is still quite a lot of egg yolk in their stomachs which they use as food.

After four or five days the tadpoles develop mouths and can feed. In the ponds and ditches of Africa in which they normally live, they eat microscopic green plants in the water.

In the laboratory it is easier to feed them on ground-up, dried nettle leaves, looking like a green powder. It is best to do this by placing about a teaspoonful of the nettle powder in a piece of nylon (a nylon stocking would do) about 6 inches square. Make this into a bag with your fingers and soak it in the aquarium water. The nettle powder soon becomes moist and by drawing the bag to and fro through the water, the fine green particles quickly disperse. Watch the behaviour of the tadpoles as you do this. How do they react? Do they remain clinging to the sides of the aquarium or do they swim about?

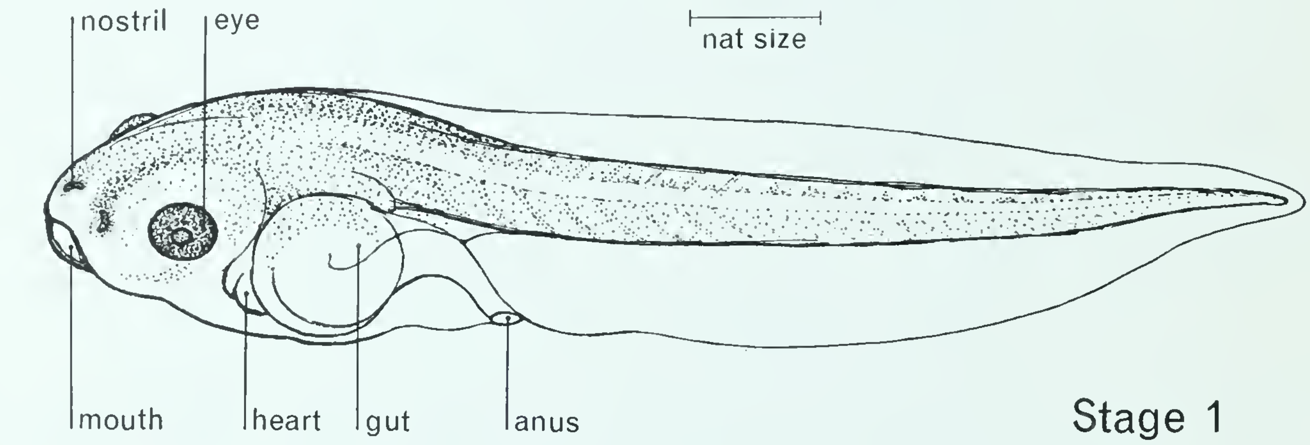
6.22 The tadpoles grow and develop

If you keep the water in the tank at 23°C, you will be surprised how quickly the tadpoles grow in length and develop new parts to their bodies.

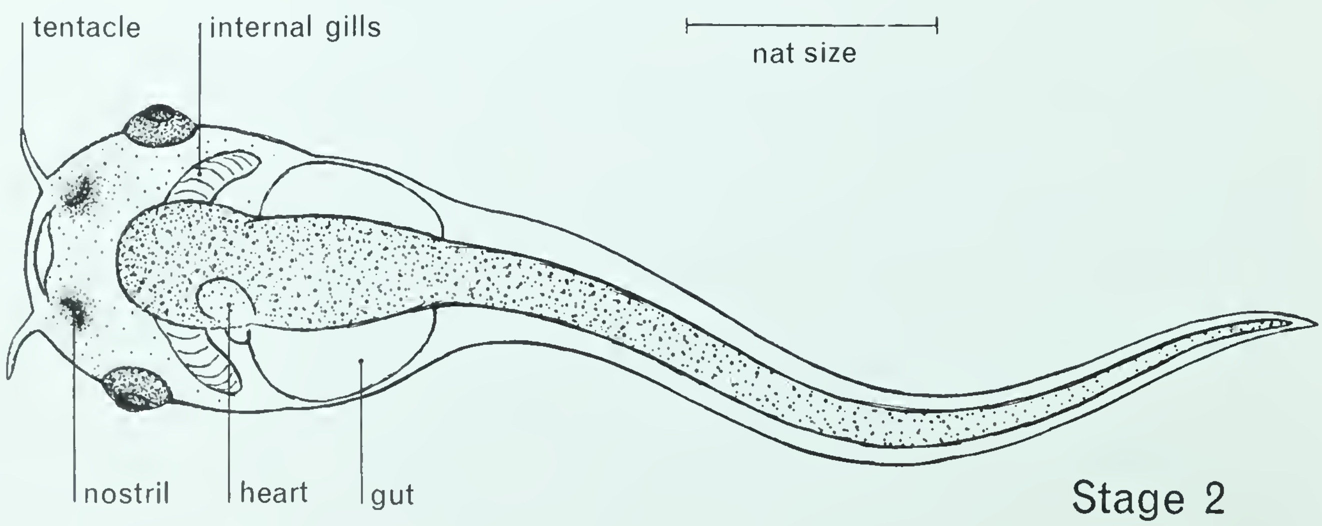
Figure 77 shows drawings of four stages in development which you should watch for and which are described below:

Figure 77
The stages of growth of the *Xenopus* tadpole.

Stage 1
About five days old. The tadpole has developed a mouth and nostrils. It uses its tail for swimming about with darting movements.



Stage 2
About eight days old (ventral view). Note the tentacles just beginning to grow; the mouth has got wider.



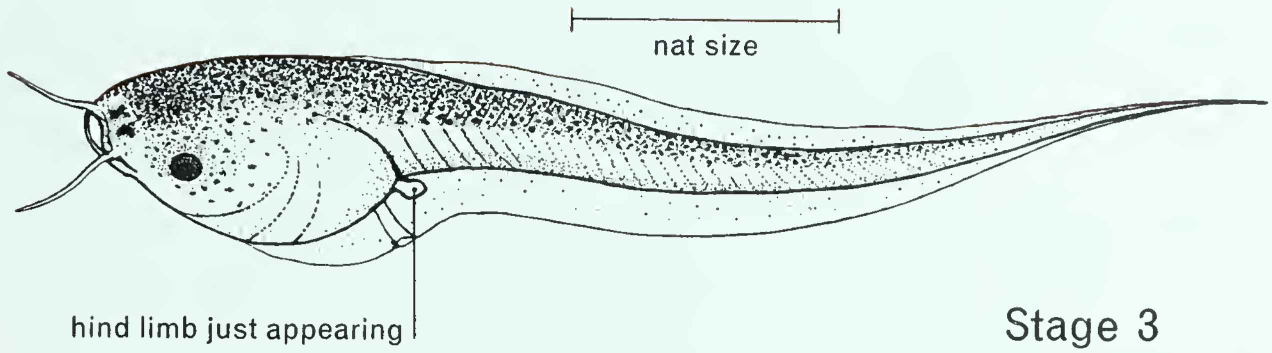
Stage 1. The tadpoles start to breathe air

At about four or five days old, the tadpole has just lost its external gills and its mouth is developing. When this happens it is growing lungs and starts to come up to the surface to gulp air. The tadpoles swim about the tank with darting movements, or hang head downwards with their tails flickering. In this position they are drawing in the particles of nettle powder through their mouth and sieving it out of the water through slits on either side of the head.

Stage 2. The tadpole develops tentacles

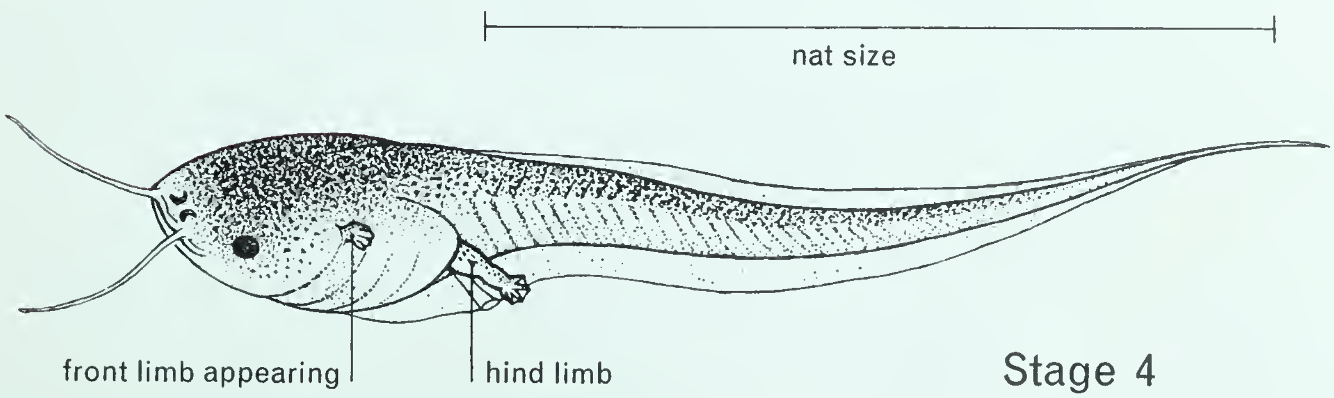
When the tadpole is about eight or ten days old, you will find that there are two small tentacles developing at the front of the head. The mouth has got larger and you can make out the eyes and nostrils. The tadpole gulps water containing nettle powder which is sieved out of the water as it passes over the sieves on either side of the inside of the mouth. Under a binocular microscope the sieving

Stage 3
About eighteen days old. The tentacles have grown longer and the mouth wider. The hind limbs are just appearing. The tail has lengthened and become pointed.



Stage 3

Stage 4
About thirty to thirty-six days old. The tentacles are very long. The hind legs now have five webbed toes. The forelegs, with four fingers showing, have pushed through the skin of the head, just in front of the hind legs.



Stage 4

apparatus can be seen through the transparent skin, as well as the nettle powder circulating in the gut and the blood flowing through the heart.

Stage 3. The tadpole develops back legs

When about twelve to eighteen days old, a small bulge appears at the back of each side of the head of the tadpole. These bulges are the back legs starting to develop. The tentacles have also grown longer.

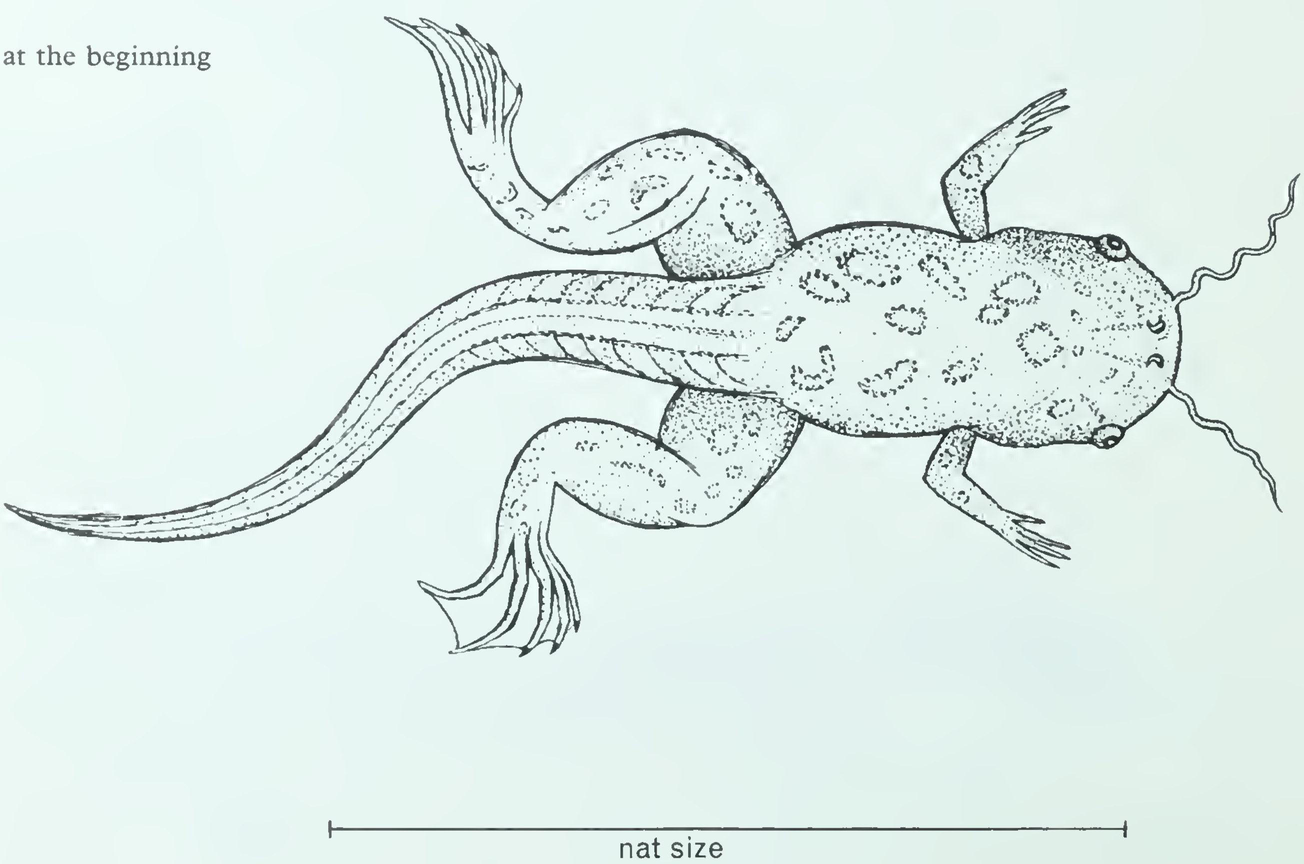
Stage 4. The tadpole develops front legs

At about five or six weeks old the tadpole has grown very large (it may even reach 80 mm in length). The tentacles are very long and the front legs, with four fingers showing, can be seen on either side of the head. You will find them in front of the back legs. These legs are now well developed, with webbing between the toes. The tadpole now swims about using its webbed feet as well as its tail. The tadpole will not now grow any longer.

6.23 The tadpoles change into toads

When the tadpoles are about seven or eight weeks old you may notice some strange things happening. They are now quite large (they may be as much as 80 mm long) and are beginning to look like little toads although they still have tails (see figure 78). At this

Figure 78
A *Xenopus* tadpole at the beginning of metamorphosis.



stage you should keep the water in the tank fairly shallow so that the tadpoles can easily reach the surface to obtain air.

1. Take one of the tadpoles out of the tank with an aquarium net and put it into a shallow dish of aquarium water. What do you notice? Are the tentacles curled and starting to shrivel? Is the skin looking more like that of the adult toads? Has the mouth got wider? Is the tail getting shorter? Has the front of the head changed shape?
2. Put the tadpole back into the tank and notice how it moves. Is it using its hind legs now for swimming?

A few days after you have noticed these changes the tadpoles will have lost their tails altogether and become little toads. This rapid change from one form to another – from tadpole to toad – is called *metamorphosis* (Greek, *meta* = after, *morphos* = form). Such changes from tadpole to adult occur in all kinds of frogs and toads, also in newts as well. Insects also change suddenly from one form to another. For instance butterflies change from caterpillar to chrysalis (pupa) and from chrysalis to adult. Such changes are also examples of metamorphosis.

During metamorphosis the tadpoles stop feeding altogether but after they become little toads, they will no longer feed on nettle powder but need a meat, or carnivorous, diet. As the tadpoles change into toads they should be removed to another tank and must be fed at first on small living animals such as water fleas (*Daphnia*), blood worms (*Tubifex*), or the small white worms from compost heaps (enchytraeids). Soon they can be given shreds of raw sheep's heart, liver, or small earthworms.

6.24 Comparing the development of *Xenopus* tadpoles with those of the common toad (*Bufo bufo bufo*)

Should you find any toadspawn (or frogspawn) you may be able to compare the development of the tadpoles with those of *Xenopus*. If so, try to answer these questions:
a. How long do tadpoles of the common toad keep their fringed gills?
b. After they have lost these external gills how do they breathe? Do they come up to the surface and gulp air like the *Xenopus* tadpoles?
c. Do toad tadpoles have tentacles on the front of their heads?
d. How old are they when they start to grow (*1*) their back legs, (*2*) their front legs, and (*3*) when they metamorphose?

6.3 Reproduction in mammals

We have been watching the development of eggs laid by *Xenopus*, or our own common frog (*Rana temporaria*) or toad (*Bufo bufo bufo*). But most fish as well as a great many animals without backbones, also lay eggs which develop outside the body. Most reptiles lay eggs too and in figure 79 you can see a young alligator just hatching. All birds lay eggs and in the last chapter we watched an embryo chicken growing inside an egg. But the group of animals – the mammals – to which we belong, do not lay eggs; instead the eggs are kept inside the body of the mother in a special place where the embryos develop. When the young mammal has reached a certain stage of development, it is born and starts to live outside the mother.

Figure 79
A young alligator hatching from an egg × 2. *Photo by Mirapic.*

6.31 The reproductive organs of the rat

In Chapter 1 there are pictures of some mammals (figure 14) and notes underneath them giving some of their characteristics. For instance, two things we learnt about the class Mammalia were that their young are born alive and that the young are suckled from mammary glands. The rat is a typical mammal.

Look at the drawings of male and female rats in figures 80 and 81, dissected to show the parts of the body which are concerned with producing baby rats. These special parts are called *reproductive organs*. Compare the drawings with the dissected rats and see if you can find the parts labelled in the drawings.

In the male rat the reproductive organs consist of the *testes* (one on each side) in which the sperms are made and a tube called the *vas deferens* leading from each testis to the *penis* down which the sperms travel.

In the female rat the reproductive organs are quite different. There is an *ovary* on each side of the body but it is small and rather

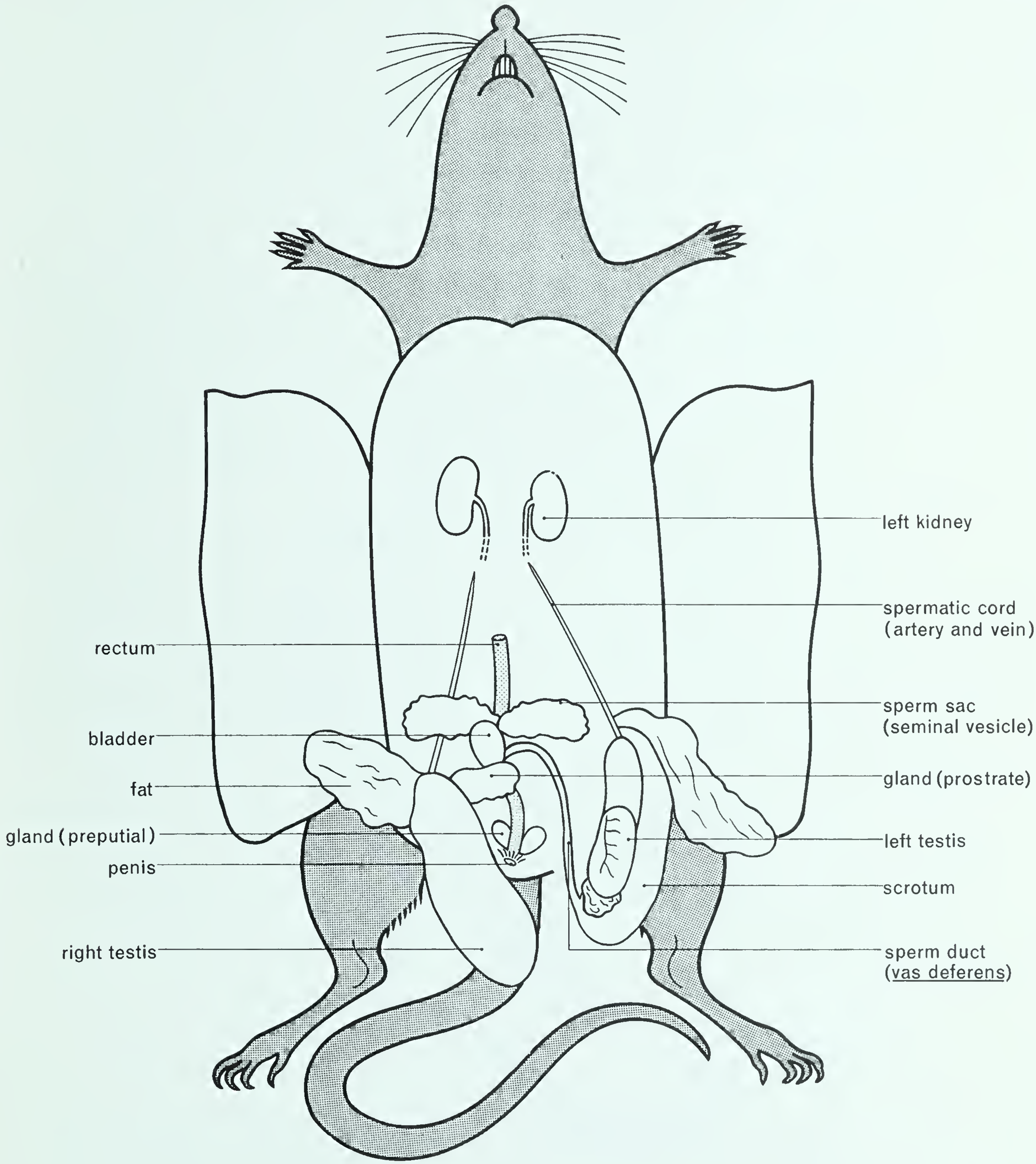


Figure 80
Male rat dissected to show the reproductive organs. The left scrotum has been opened to show the testis.

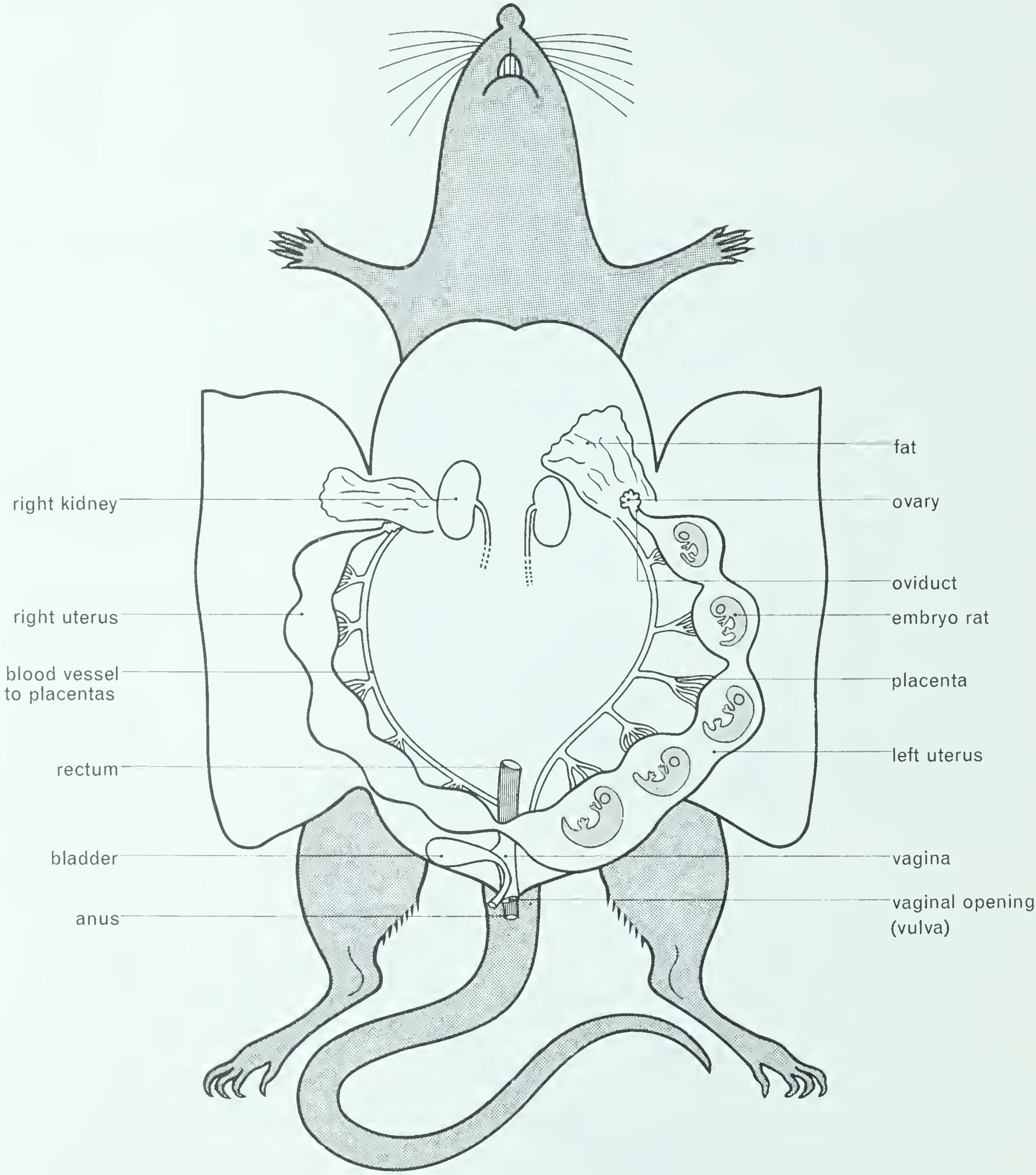


Figure 81
Female rat dissected to show the reproductive organs. The left uterus has been opened to show the embryos.

difficult to find. The eggs, which are formed in the ovary, are only about 0·1 mm in diameter – far too small to see with the naked eye. You can see just how small a rat egg is compared with a hen's egg, if you look at figure 59.

As they are formed the eggs are shed from the ovary and travel down a small tube, the *oviduct*, to the *uterus*. The right uterus in the drawing in figure 81 has bulges all along it. If you look at the left uterus in the dissected rat, it has been cut open and you may be able to see that each bulge is really a baby rat. There may be as many as five or six embryo rats in each uterus, and each embryo is attached to the wall of the uterus by blood vessels and other tissues which together form what is called the *placenta*. When they are ready to be born, the baby rats leave each uterus, one at a time, travel down the single *vagina* and are born into the outside world through the vaginal opening.

With a blunt seeker carefully lift one of the embryos and find out how it is attached to the wall of the uterus. Each embryo lies in a sac containing fluid. With a hand lens examine the embryo. Can you make out the head and limbs? Count the embryos in each uterus.

6.4 The cycle of reproduction in man and other mammals

We have seen that inside the body of a mammal such as the female rat, there are two ovaries in which the egg cells are produced. Human beings are also mammals and the ovaries in a woman produce very small eggs. Look again at figure 59 and you will see just how small the human egg is compared to the size of a hen's egg.

The eggs of all mammals ripen in the ovaries and are released at regular periods or cycles. The length of the cycle varies in different mammals. Thus mice produce ripe eggs every 4 days and pigs every 21 days. A woman normally produces one egg every 28 days. Like humans, some other mammals produce only one egg at a time. That is why elephants, cows, and seals usually give birth to a single young one while such mammals as dogs, cats, rabbits, mice, and rats produce more than one egg at a time and so give birth to several young.

Figures 82 and 83 are diagrams of the reproductive organs in man.

6.41 Fertilization and development in man

A ripe human egg which is produced once every 28 days, travels down the oviduct (fallopian tube) where it can be fertilized by sperms in the same way as a hen's egg is fertilized inside the oviduct of the hen. Sperms, formed in the testes, are introduced in a liquid called seminal fluid, into the vagina by means of the penis, so that no sperms are wasted. The sperms (see figure 84) swim with their tails, up the moist vagina to the uterus and into the oviduct where the egg is then fertilized (see figure 85).

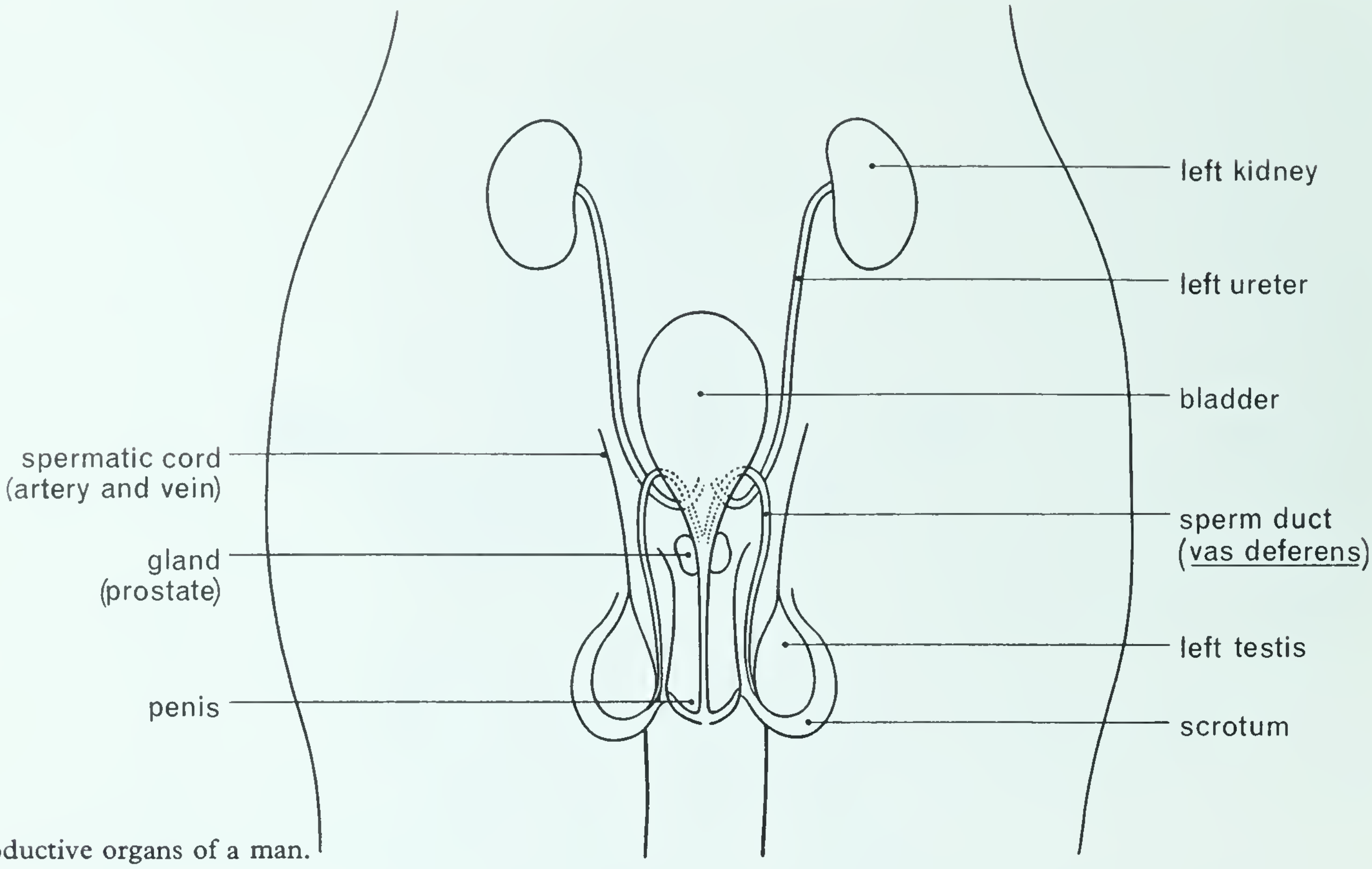
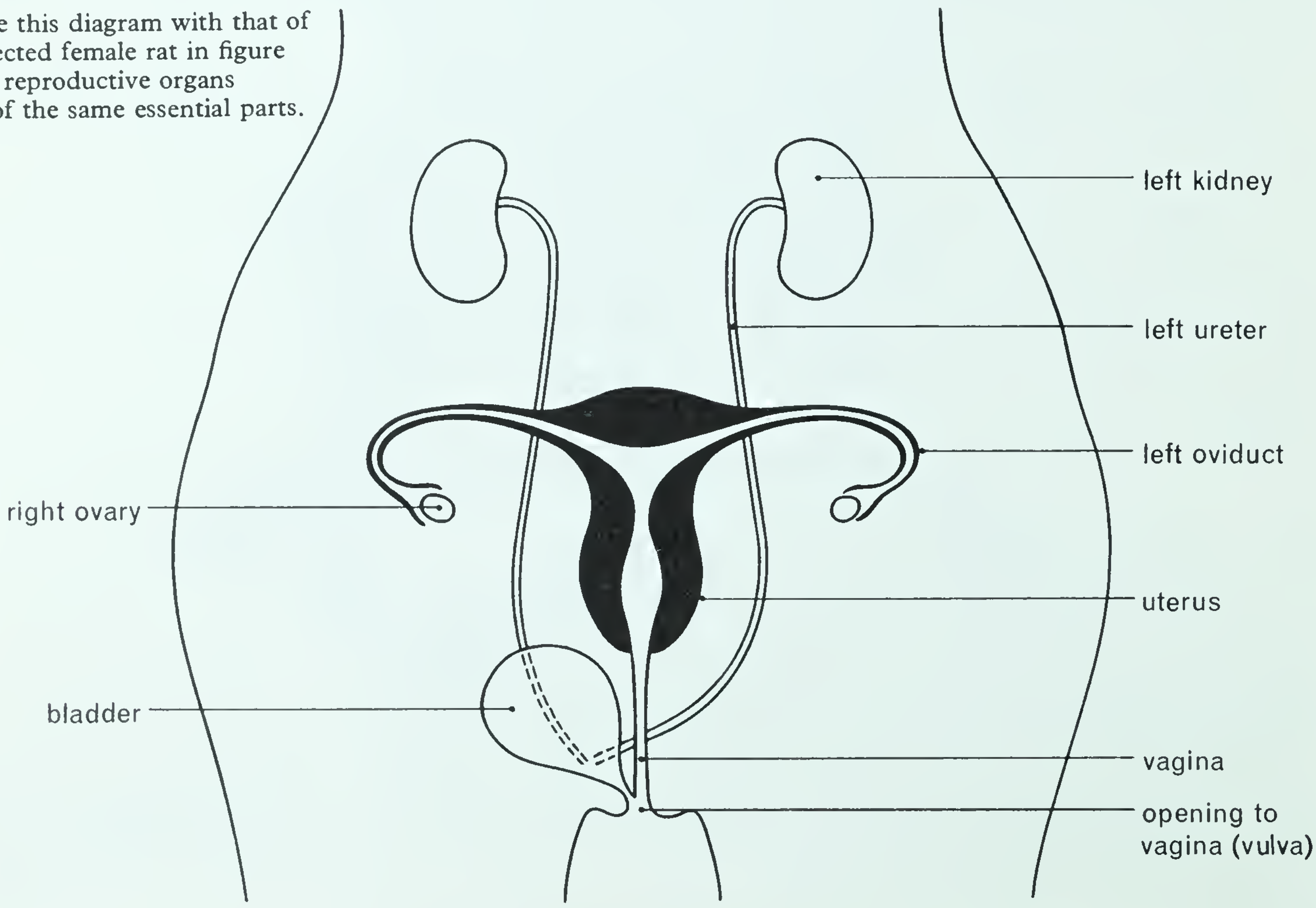


Figure 82
The reproductive organs of a man. Compare this diagram with that of the dissected male rat in figure 80. The reproductive organs consist of the same essential parts.

Figure 83
The reproductive organs of a woman.
Compare this diagram with that of the dissected female rat in figure 81. The reproductive organs consist of the same essential parts.



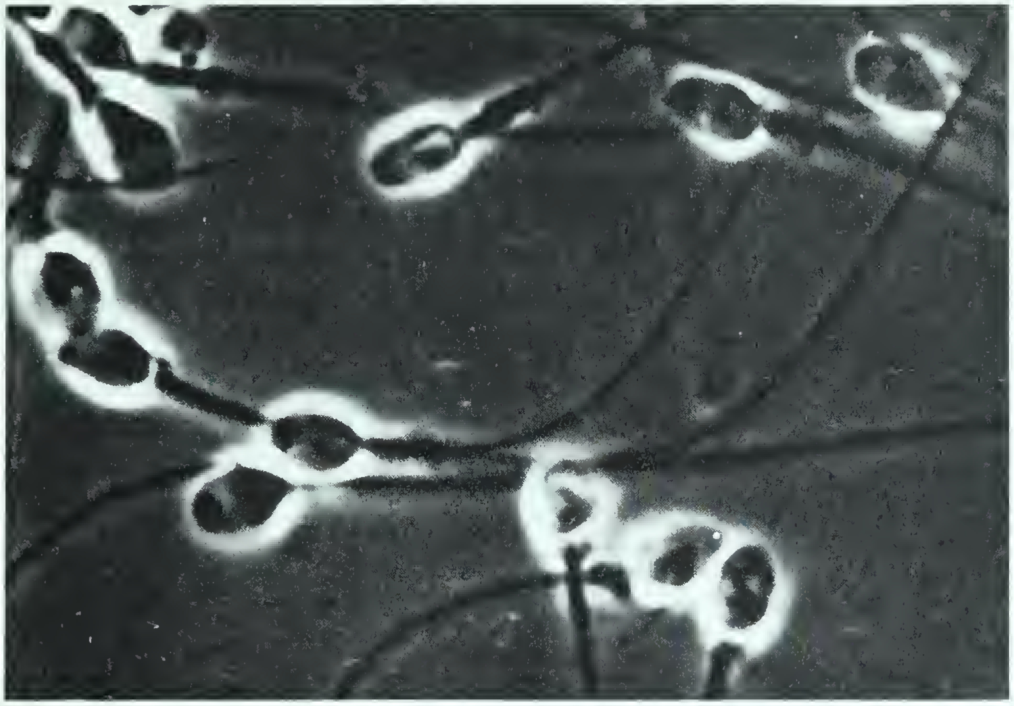


Figure 84
Human sperms × 1600 approx. The sperms have been photographed in reflected light. Note the heads and strong tails of the sperms. *Courtesy Landrum B. Shettles*, Fertility and Sterility, *Vol. 12, P. 22, 1961.*

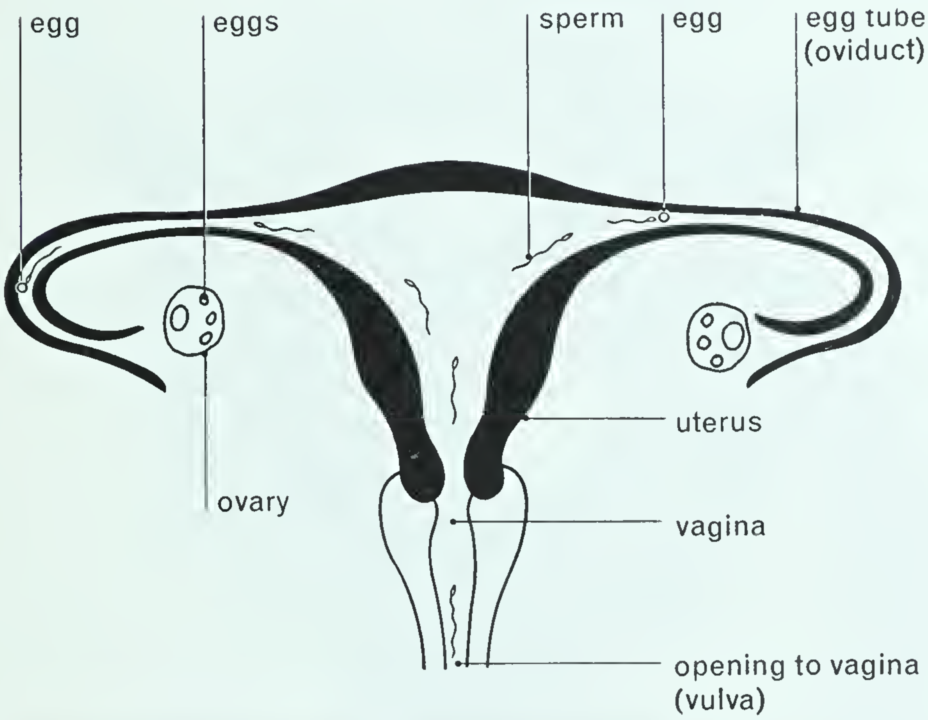


Figure 85
Internal fertilization in man.
An egg has been released from the ovary on the left. Sperms swim up the vagina into the uterus and along each egg tube.

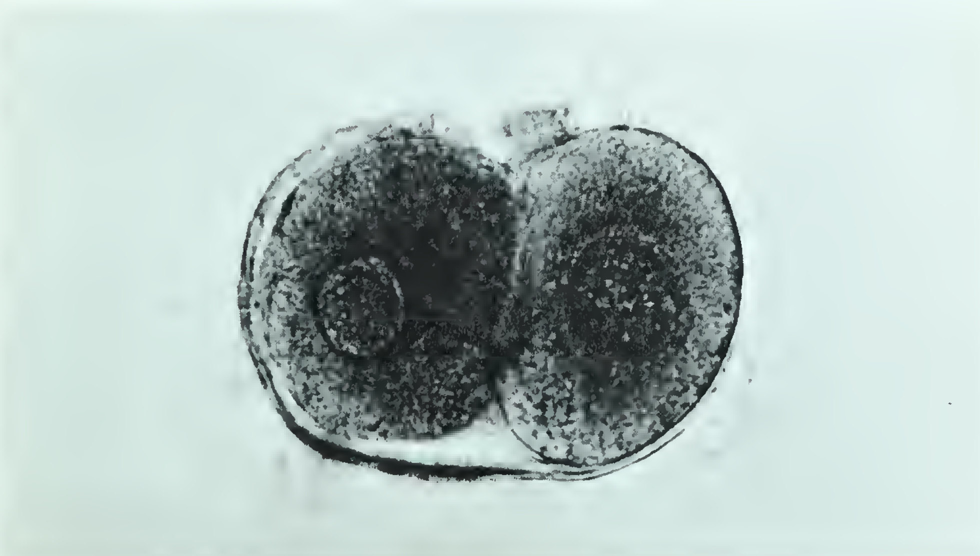


Figure 86
A fertilized human egg dividing into two cells × 400 approx.
Note the nucleus in each cell. *By courtesy of the Carnegie Institute of Washington.*

Fertilization is a trigger that sets off a chain of events. The egg starts to divide into two cells (see figure 86), then into four, eight, and so on in the same way as the starfish egg and the egg of the tube worm, *Pomatoceros*.

Meanwhile the uterus prepares to receive the ball of cells which is the young embryo. Its walls become thick, spongy, and rich with blood. The embryo travels down into the uterus and becomes embedded in the thick wall and during the next few days a mass of blood vessels, called the *placenta*, is formed in the wall of the uterus. Soon the embryo floats free in the uterus surrounded by fluid and attached by a cord to the placenta. Through this cord, called the *umbilical cord*, the embryo is nourished with oxygen and food in solution, from the blood of the mother. Figure 87 shows an embryo human baby lying in the uterus. The fluid surrounding the embryo helps to protect it just as the fluid inside the hen's egg protected the chick embryo.

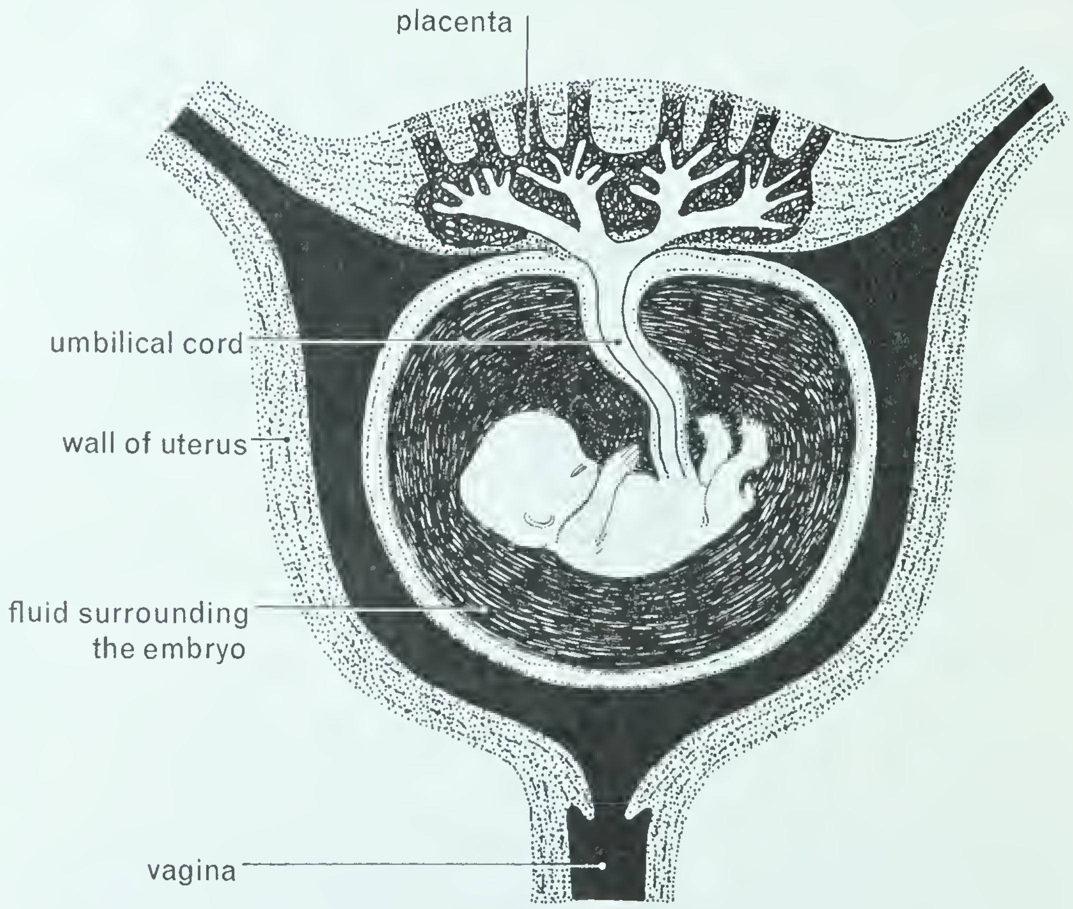


Figure 87
Embryo human baby lying in the uterus.
The embryo is attached to the placenta by the umbilical cord.
Reproduced from The First Nine Months *by G. L. Flanagan, published by William Heinemann Medical Books Ltd.*

The drawings in figure 88 show two stages in the growth of a human embryo inside the uterus of the mother. At four weeks old you can already make out the eye and the arms and legs growing. Compare this drawing with that of the $3\frac{1}{2}$ day old chick embryo in figure 62. Are they at all alike ? At eight weeks the embryo, although only about one inch long, already looks like a baby. Its head is very large compared to the rest of the body, but the eyes, ears, nose, and mouth are already developed, and also the fingers and toes.

Figure 88
Two stages in the growth of the human embryo.

1. About four weeks old. The eye, arms and legs are developing. At this stage the embryo has a tail.

2. About eight weeks old. The nose, mouth and ears are developing, also the fingers and toes. The embryo still has a small tail.

6.42 The birth of a baby

It takes nine months for the human embryo to grow inside the mother. Figure 89 shows the baby now fully developed and ready to be born. It lies in the uterus which enlarges as the embryo grows with its head near the opening of the birth canal (the vagina) but still attached to the placenta by the umbilical cord. By now the baby weighs about 8 lb and sometimes more than this.

When the baby is ready to be born, the muscles of the uterus contract rhythmically to push the baby out. The fluid which surrounds the baby flows away and the baby is born head first. The umbilical cord is cut by the doctor and the baby takes its first breath to fill its lungs with air.

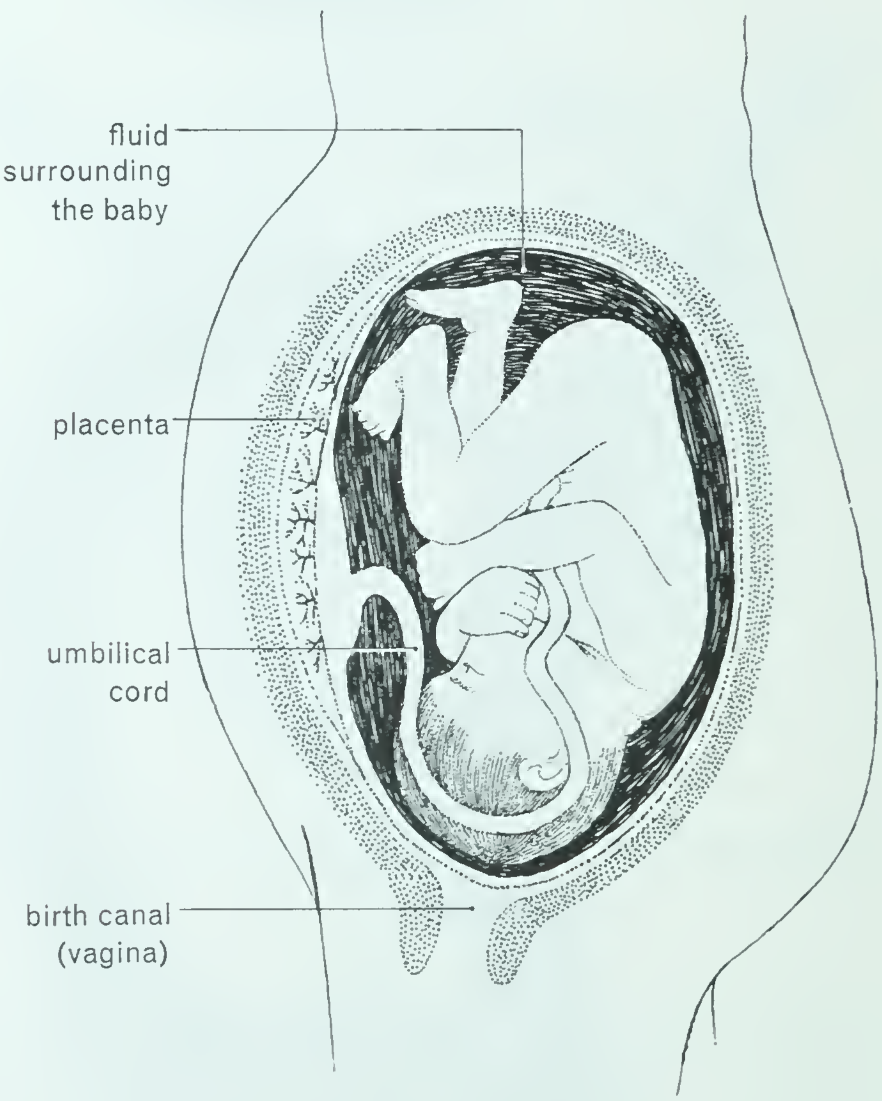


Figure 89
A human baby ready to be born. The baby is lying inside the uterus of the mother, with its head near the opening of the vagina.

6.43 What happens if the human egg is not fertilized?

As we have learnt, a woman produces an egg every 28 days and this continues from the time she is about twelve or fourteen years old until she is about fifty. Those eggs which are not fertilized break up before they reach the uterus. Meanwhile the uterus, which has prepared to receive the egg, throws off the spongy part of its wall and some blood is discharged through the vagina. This is called *menstruation* and lasts for a few days during each reproductive cycle of 28 days.

Men produce sperm, from the age of about thirteen or fourteen, and can go on doing so most of their lives, although their power to do so decreases as they get older.

6.5 How long does it take for a mammal to develop in the uterus?

As a general rule, the longer the period within the uterus, the further the young mammal is developed at birth. The chart in figure 90 shows the number of weeks that some mammals take to develop. This is called the *gestation period.*

6.51 Protection of the developing embryo

In figure 59 the sizes of mammals' eggs are compared with those of fishes, birds, and other animals. Considering the size of adult mammals it may seem strange that their eggs are so small and have so little yolk. However, it is not so odd after all when we remember that the egg develops entirely inside the mother and is kept warm

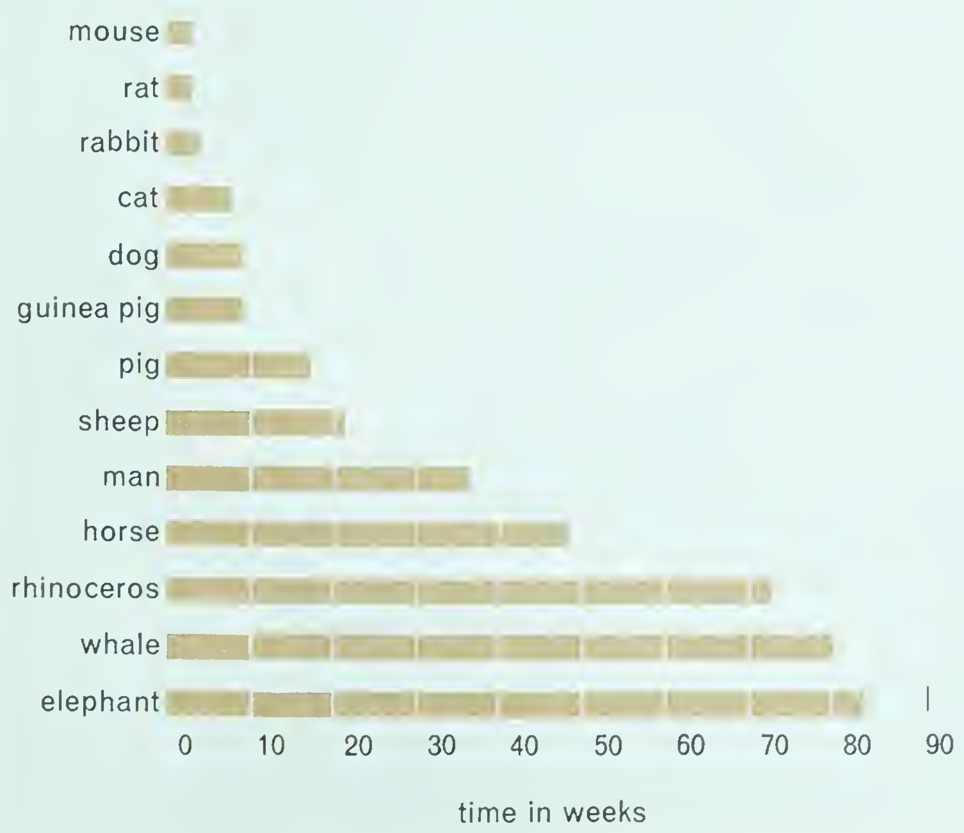


Figure 90
Chart showing the gestation periods of some mammals.
From this chart, would you say that the size of a mammal, when it is fully grown, is related to the length of its gestation period?

and nourished by her. This is the reason why there is no need for a food store inside the egg. Hence its minute size.

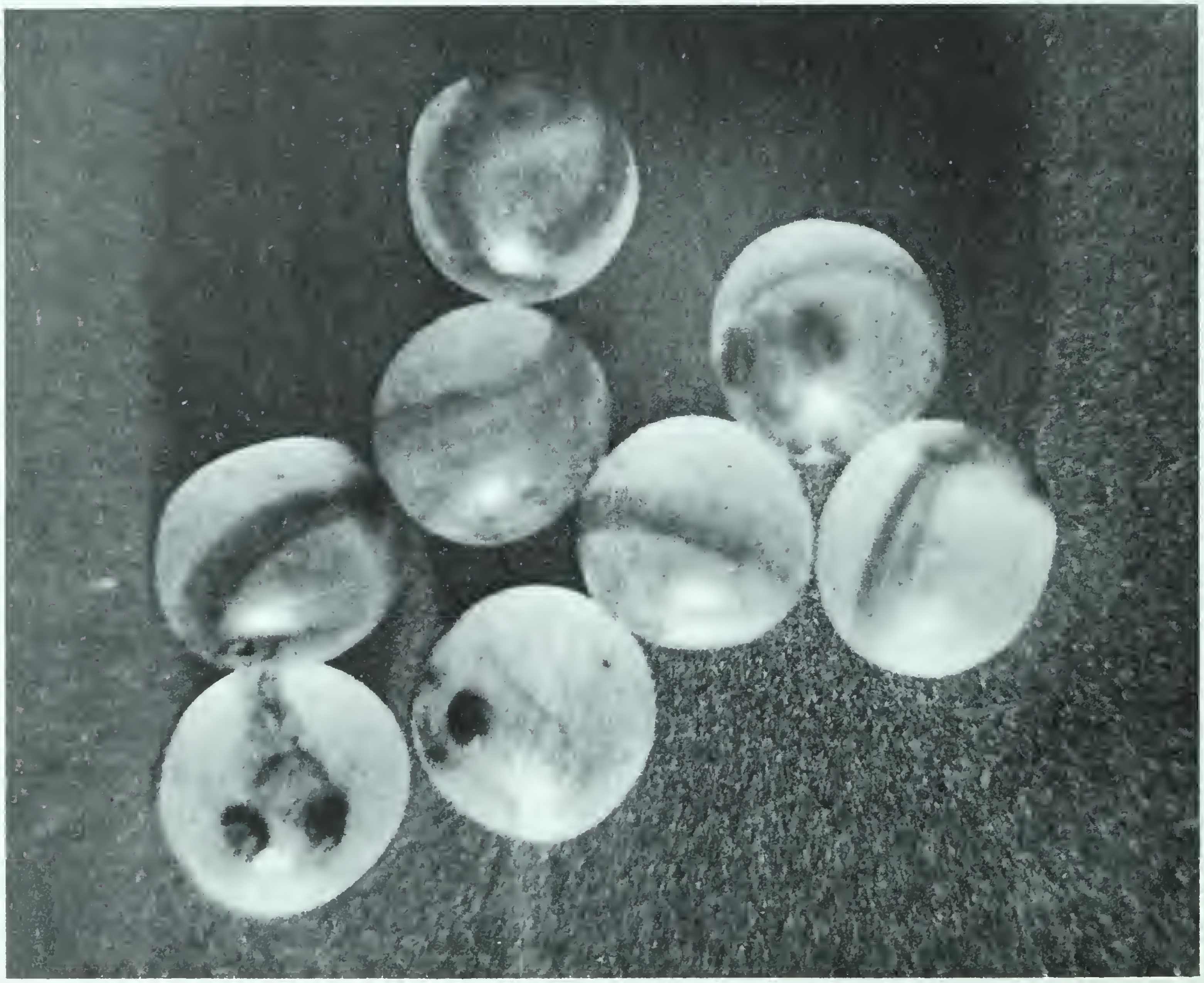
The needs of a developing embryo are food, water, air, and warmth. We have seen that in the hen the embryo chick develops inside the egg which contains yolk on which the embryo feeds while it is growing, and white (albumen), which surrounds the embryo, providing water and protecting it against vibrations. The hen's egg also has a hard shell which protects the contents of the egg, at the same time allowing air to pass into and out of the egg. Different kinds of birds lay different sizes of eggs. A large bird such as an ostrich lays a very large egg, while a small bird such as the wren lays a small egg. The smallest bird of all, the humming bird, lays an egg only half an inch long. But the eggs of all birds are much the same in their general structure as that of a hen and the chicks develop nourished by the yolk.

Figure 91
Trout eggs developing.

1. The eggs are nearly ready to hatch × 8. Notice the embryos inside the transparent eggs.

2. A young trout one hour old × 10. Notice that the yolk sac is still attached to it; this provides food for the young fish. *Photos F. Lane (W. T. Davidson).*

1



Reptiles such as tortoises, and most kinds of snakes and lizards also lay eggs which contain yolk and a watery fluid, the egg being enclosed by a leathery shell. In these animals the embryo inside may become well developed before the egg is laid. Amphibians such as frogs, newts, and salamanders lay their eggs in water like *Xenopus*. The egg has no shell, contains some yolk, and is surrounded by a layer of jelly to protect it. Most fish also lay eggs in water, the egg being protected by a jelly or leathery covering. Thus in both amphibians and fish the embryo obtains water from the surrounding sea or pond and not from inside the egg.

6.52 The care of the young animal

Figure 91 shows the eggs of a trout. Inside the egg you can see quite a lot of yolk and even after hatching the young trout still has

2

a yolk sac attached to the body and uses the yolk as food for the first few days of its life outside the egg. We found this was also true of *Xenopus* tadpoles (see section 6.21), and because of the yolk in the tadpoles' stomachs it was not necessary to feed them for the first few days after they had hatched.

Once their eggs have been laid most fish and amphibians leave them to hatch on their own. Some fish such as salmon and trout make a kind of nest (called a redd), in the bed of a river, scooping out gravel to form a hollow in which the eggs are laid. The eggs stick to the gravel and are thus prevented from being washed away. But as soon as the young fry hatch they have to fend for themselves. In a few fish the parents protect the eggs. In the sea horse, for instance, the female lays her eggs in a special brood pouch on the underside of the male (see figure 92). They are carried round in the pouch until they hatch and even after this, the male will keep the young in the pouch for a few days longer. Should any of the fry stray he sucks them up into his mouth and blows them back into the pouch. Figure 93 shows a group of young sea horses taken from the pouch of a male.

On the whole, examples of the care of young by their parents are rare in fish, amphibians, and reptiles. It is not until we come to the birds that parental care becomes more highly developed. A hen makes a nest and sits on her eggs to incubate them for twenty-one days, when the chicks hatch. The length of time the eggs are incubated varies greatly in different kinds of birds. In the starling, for instance, it is about twelve or thirteen days, and in the rook fifteen or sixteen days, in the budgerigar eighteen days; while some sea birds take as long as sixty days over incubation.

The hen's chick is fully feathered and able to peck food and to drink as soon as it hatches. But the newly hatched chicks of many birds are quite naked and helpless. This is so in most of our common garden birds and the chicks must be fed by the parents, often for several weeks, before they can select food for themselves and leave the nest.

In mammals, including man, parental care is much more developed and the young are not only protected by the parents but suckled with milk by the mother for some time after they are born.

Summary

The eggs of land animals are fertilized inside the body of the mother; after fertilization the eggs start to divide and grow into an embryo. Most fish, amphibians, reptiles, and birds lay eggs containing yolk and the embryo develops inside the egg until it is ready to hatch. In man and other mammals, the eggs develop inside the mother's body and are nourished by her, and the young are born alive.

Birds and mammals look after their young, feeding and protecting them until they can fend for themselves.

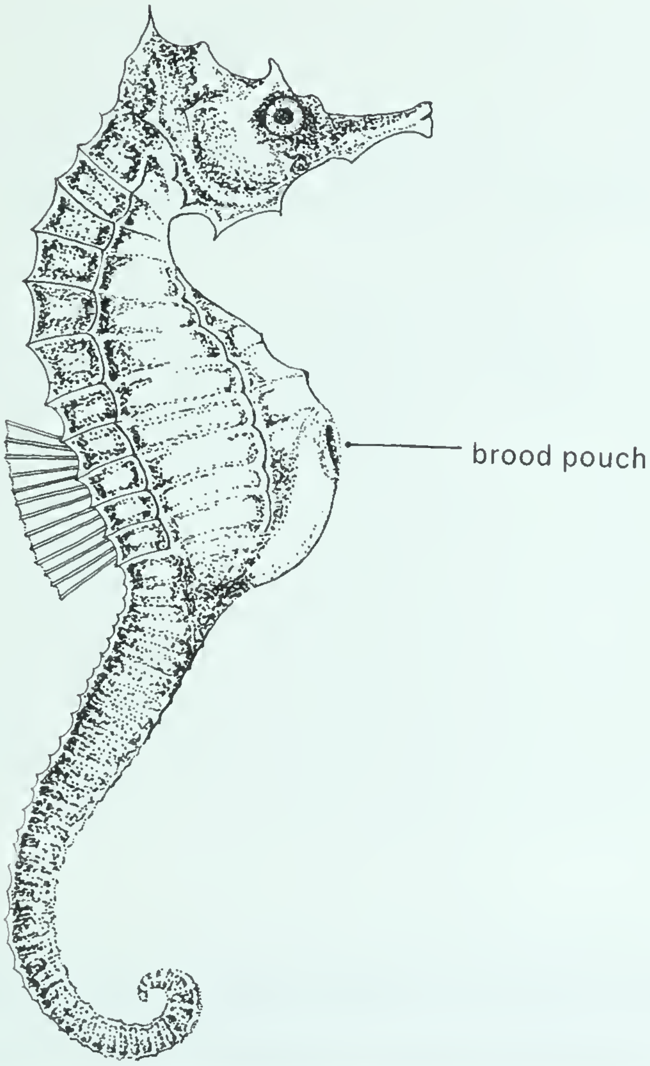


Figure 92
A male sea horse. The brood pouch has an opening in front from which the young can escape.

Figure 93
Young sea horses.
They spend part of their lives carried in the brood pouch of the father. Notice that each still carries a yolk sac upon which it relies for food while in the pouch.
Photo, Mondiale.

Background reading

The dragon of the pond

Looking into a pond we may notice a suspicious movement at the bottom which proves to be a female smooth newt pushing her way slowly between the stems of water plants with her pale brown body. It is nearly April and she is fat with the eggs inside her abdomen.

Presently a male newt (see figure 94) appears with a long jagged crest running down his back. He looks twice as large as the female and is in his mating colours of orange and black spots – a veritable dragon of the pond. He stalks the female, following her closely as, apparently not noticing her suitor, she walks slowly over the stones and dead leaves.

All at once the male darts forward until he is in front of his wife-to-be, nudges her head with his nose, and then turns to face her, blocking her way. Bringing his tail round to the side of his body, he vibrates it violently in the water so that it seems to quiver with excitement. He is giving off a liquid, from glands inside his cloaca which smells strongly to other newts. The vibrations of his tail not only help to waft the scent to the female, but are also designed to excite her.

Figure 94
Male and female smooth newt, *Triturus vulgaris*.
During the breeding season the male grows a crest along his back. He stays near the female while she is laying her eggs. *Photo, F. Lane (W. J. Howe).*

The female newt has stopped quite still now, making no apparent response to his advances. We would be wrong, however, if we interpreted her inactivity in this way, for the strangest things are about to happen. Moving closer still, the male drops a small packet, about 2 mm in diameter, containing sperms just in front of the female. Quickly she moves over the tiny object and presses her cloaca onto it. The precision with which this is done is quite astonishing.

Once inside the cloaca of the female, the sperms free themselves and move by means of their long tails into a special internal pocket. Here they may live for several months.

The female is now ready to start laying her eggs. As each egg descends the egg tube and passes the pocket in which the sperms are stored, it is fertilized. The female newt lies amongst water weeds and lays each egg singly. This she does with extreme care, using her back legs to fold each sticky egg in a small leaf. As many as eighty to a hundred eggs may be laid in this way and, since such individual care is needed, the whole operation may take several days to accomplish. All this time the male remains beside the female.

Soon the eggs start to develop into embryos (see figure 95) and after about two weeks the newt tadpoles struggle free, complete with tails, four legs, and a fringe of gills on either side of their heads

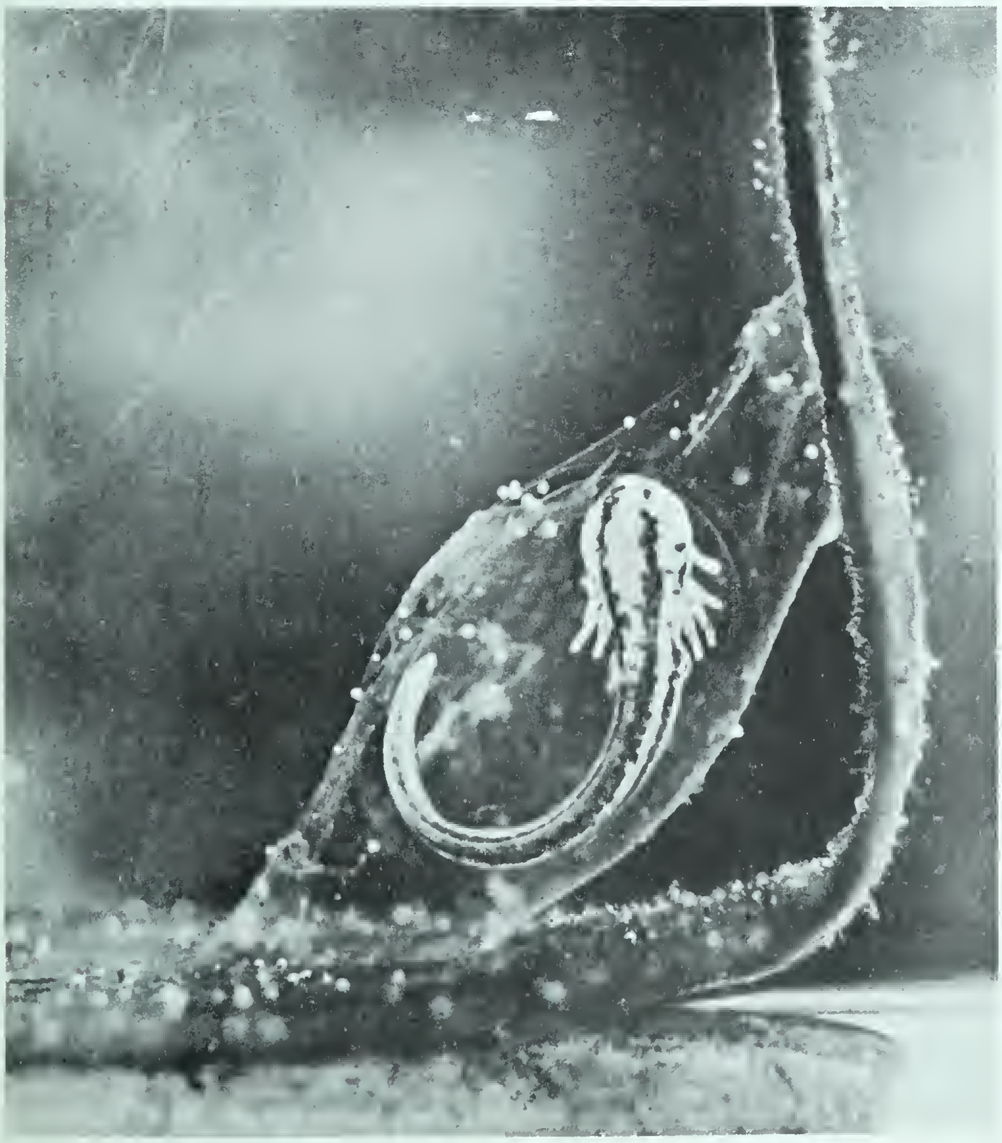


Figure 95
A young newt tadpole inside an egg. The tadpole, with external gills but no legs, lies curled up inside the transparent egg.
Photo, Mondiale.

Figure 96
A newt tadpole a few weeks old. It has now got four legs which grow soon after it hatches from the egg. *Photo by John Clegg.*

(see figure 96). It may take several months before the tadpole has grown into a young newt, but normally by the autumn most of the young have left the pond, their skins now rougher in texture than when they were in the water. This is to enable them to live on land for, strangely enough, they are not to return to the pond for two or three years until they are fully grown and ready to reproduce.

Meanwhile the parent newts have also left the pond and will not return until the following spring to start their curious courtship dance all over again.

Living things multiply

7.1 The need for reproduction

Without the means for reproduction, animals and plants would soon disappear from the earth, since they would leave no individuals behind them to carry on after they were dead. Indeed this is exactly what has happened with a great many species in the past. We have already heard about some of these extinct forms. The fish-like reptile, the ichthyosaur (see figure 1), and the curious arthropod, the trilobite (see figure 2) are two animals which have become extinct and there are many other examples which you may have read about. Birds like the dodo and the great auk have become extinct within the last few hundred years.

Sooner or later all organisms die, but before this happens they must reproduce. Death and the necessity for reproduction are two other characteristics of living things which we can add to those we learned about earlier.

In the last two chapters we have been investigating various animals which possess special sex cells – sperms produced by the male and eggs produced by the female. The egg cells, once fertilized by a sperm, develop into embryos. This is called sexual reproduction.

In this chapter we are going to investigate some rather strange ways other than sexual reproduction in which animals and plants reproduce themselves.

7.11 Can new plants grow from a parent plant?

Plants can actually make new plants by splitting a part off from themselves capable, in time, of growing into another plant. You could try this with a common water plant, duckweed (*Lemna*), which is found everywhere on the surface of ponds and ditches. The duckweed plant consists of one small round leaf and a short root which trails below the surface of the water (see figure 97*a*).

1. Choose a single plant of duckweed and make a drawing of its outline, dating your sketch.
2. Shake up a little garden soil in a jam jar of water and transfer the plant you have drawn to the water, using a brush so as not to damage

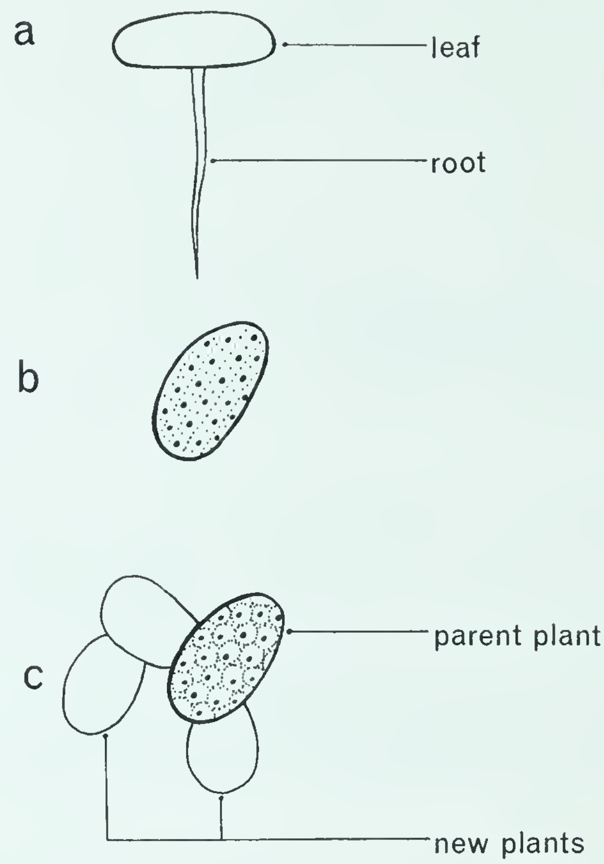


Figure 97
Lesser duckweed (*Lemna minor*).
a. A single plant of duckweed seen from the side.
b. Parent plant.
c. After seven days.

it. The soil in the water will provide the food substances necessary for the duckweed to grow.
3. Leave the jar in good light on a window sill for a week and then draw the plant again.

Have any new plants grown from the parent? Your drawings at the beginning and end of the experiment may look something like figure 97*b* and *c*. Compare your sketches with those of the rest of the class. Can you now work out how the new plants have arisen from the parent? Can you see any difference between the new and the old leaves?

If the original duckweed plant has grown some new leaves, each with a small root, we shall have found two things: firstly that new plants were developed from the parent, and secondly that they are actually growing. If you now separate some of the new plants from the parent you might try to discover if they are able to live on their own.

7.12 Can new plants grow from pieces of the parent?

Unlike water plants, those on land do not often split off parts of themselves, but if pieces happen to get broken from the parent they will often make roots and grow into new plants. We could investigate this with a geranium plant.

Taking a cutting from a stem

1. Find a shoot growing out from the main stem of a geranium plant and cut it off just above a node (see figure 98).

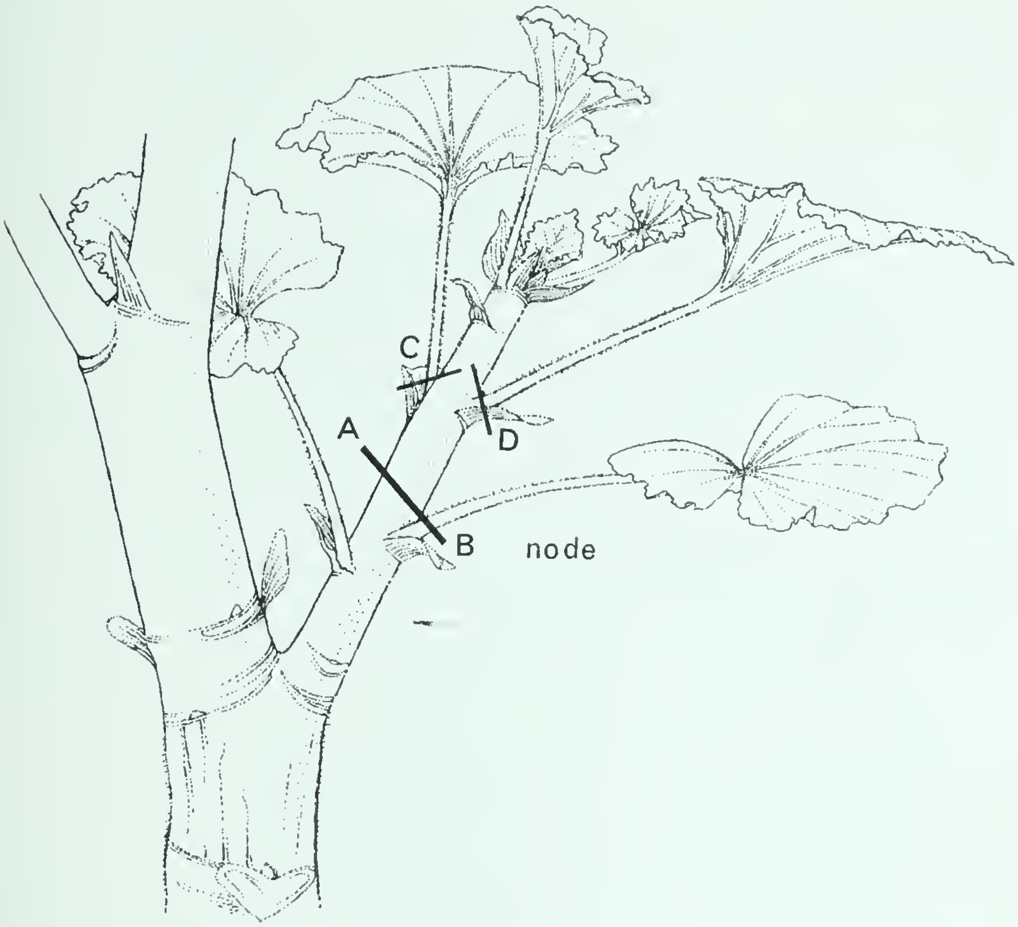


Figure 98
How to take a cutting of geranium. With a sharp knife, cut the shoot across at A – B. Remove the bottom leaves C and D of the shoot.

2. Take off the lower leaves from your cutting and leave only two or three at the top.
3. Fill a plant pot nearly full of damp soil and make a hole about 1½ inches deep near the edge of the pot.
4. Put a pinch of silver sand at the bottom of the hole and plant the cutting firmly in the hole, pressing the soil well round it. The sand ensures a supply of air to the cut end of the stem (see figure 99). You should take four or five cuttings and plant them in this way, around the edge of the pot.
5. On a label write your name and the date. If there is a flower still on the parent plant, so much the better, for you can record its colour on the label as well.
6. Put the whole pot inside a Polythene bag and tie the neck of the bag. The moisture will then be kept in the soil and you will not need to water it very often. Place the plant pot, if possible, above but not on the hot pipes.
7. After about four weeks, dig up the cuttings and see what has happened. Have small roots grown? If so, at which points? What has happened to the part of the cuttings above the soil? What has happened to the place on the parent plant from which you took the cutting?
8. If roots have developed you can now plant each of the cuttings in a separate 4 inch plant pot and water them once a week. Later on they will grow into plants with flowers. Are the flowers on each plant the same colour as those of the parent plant?

Growing root cuttings

You could try to grow new plants from pieces of root.

1. Dig up a dandelion carefully so that you have the whole plant with its root complete.
2. Cut the taproot in sections about $1\frac{1}{2}$ inches long (see figure 100*a*).
3. Fill a plant pot with moist soil and plant the portions of root so that they are just below the surface of the soil as in figure 100*b*.
4. Cover the pot with a Polythene bag to prevent evaporation of moisture from the soil. You will probably not need to water the pot.
5. After two weeks take the Polythene bag off and examine the surface of the soil in the plant pot. Can you see anything growing?
6. Dig up the root cuttings. Do you notice any sign of growth? Why do you think dandelions are such difficult weeds to get rid of in gardens?

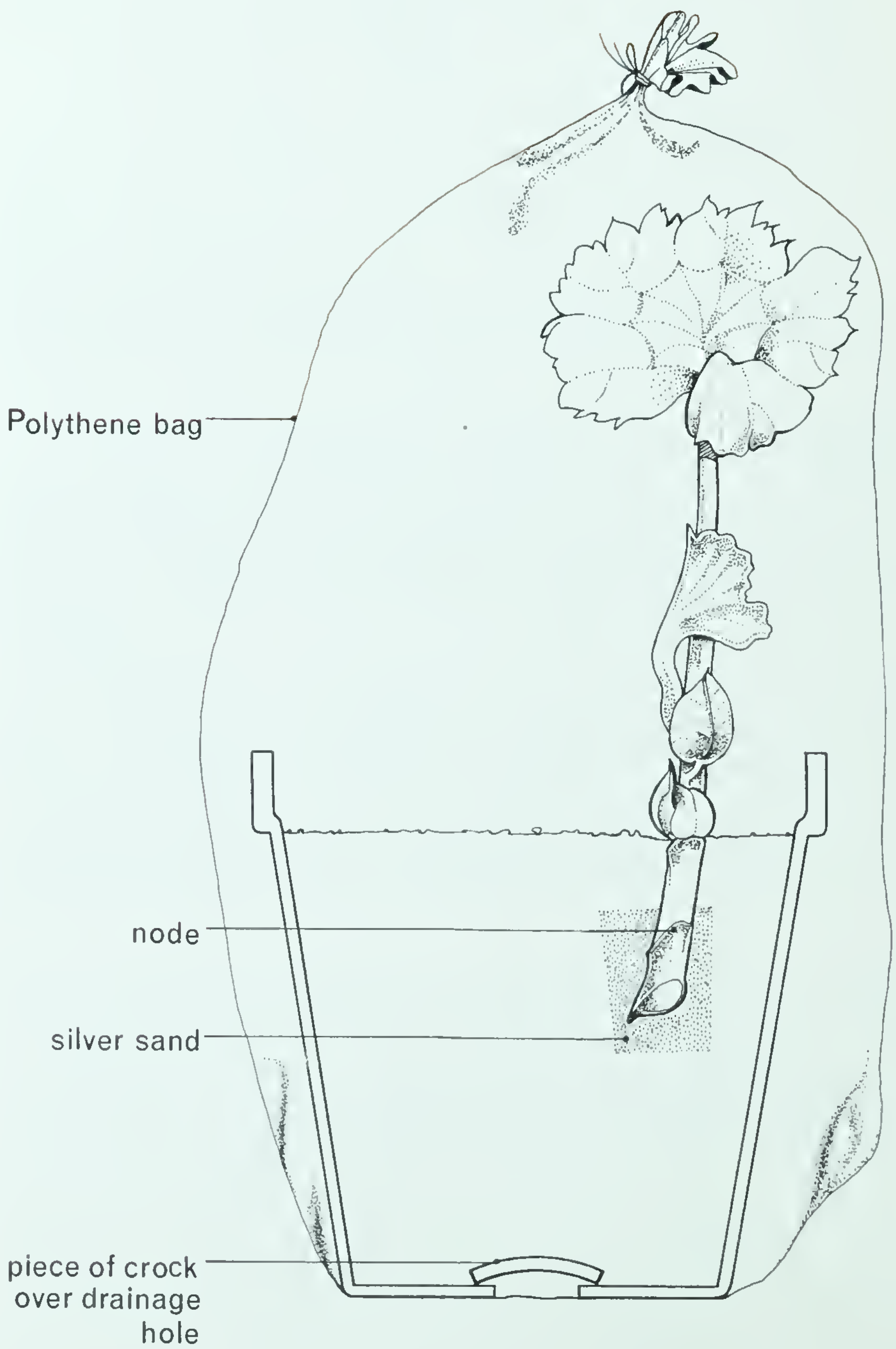


Figure 99
How to plant geranium cuttings.

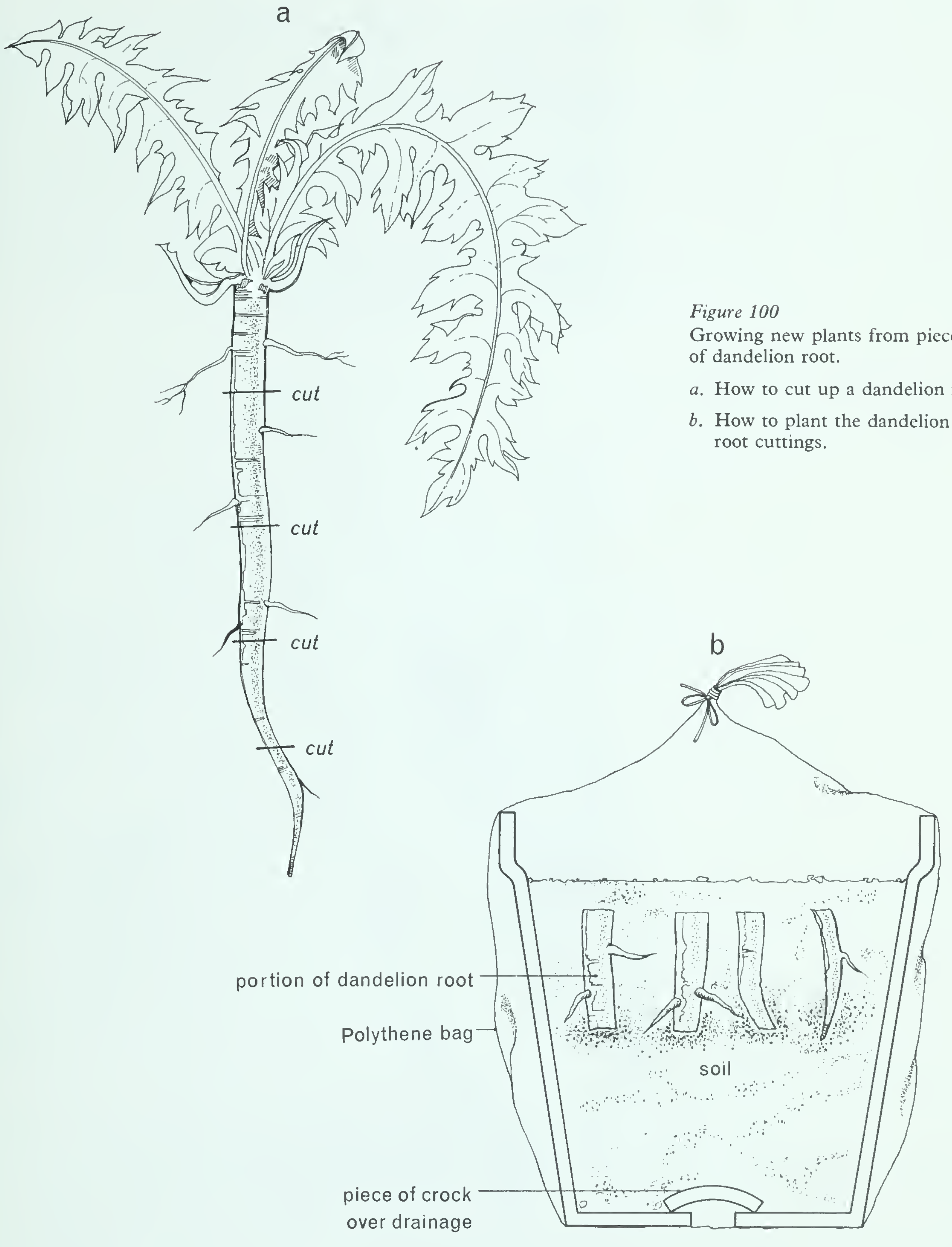


Figure 100
Growing new plants from pieces of dandelion root.

a. How to cut up a dandelion root.

b. How to plant the dandelion root cuttings.

Plants that can grow plantlets on themselves

Some plants can even grow new little plants on themselves. One plant which can do this is a greenhouse cactus *Bryophyllum daigremontianum* (see figure 101). The plantlets grow round the edges of the leaves and each has roots which hang down in the air. When they have grown to about an inch, the small plants drop off the edge of the parent leaf and if they fall on soil the roots quickly become established and new plants are formed all round the parent. In this case we have an example of a plant which actually grows complete little plants with leaves and even roots while it is still attached to the parent.

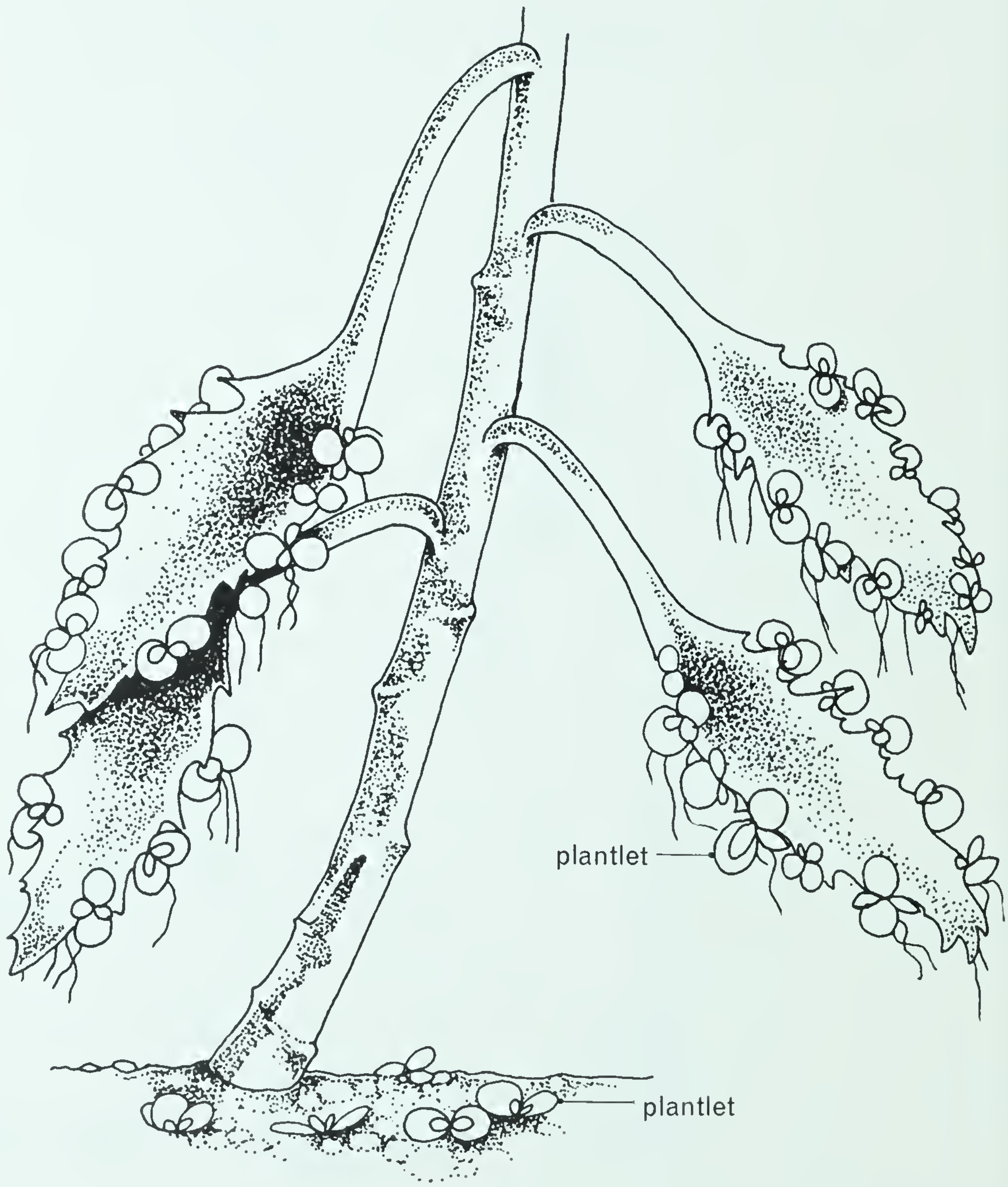


Figure 101
Bryophyllum daigremontianum.
Several plantlets have dropped off the parent plant and are growing in the soil below.

7.13 Gardeners use vegetative propagation

A large number of plants can reproduce from small pieces which eventually break away from the parent and grow into separate plants. This is called *vegetative propagation.*

Nurserymen and gardeners make use of vegetative propagation in a practical way. If they have special plants which they want to increase, they can take stem or root cuttings. This is done with carnations, chrysanthemums, dahlias, and a number of other plants.

When the leaves have died down in autumn, large herbaceous plants such as lupins, delphiniums, and phlox can be divided up for each piece of root will grow into a new plant.

7.14 Features of vegetative propagation

The geranium cuttings which you made in section 7.12 should grow into plants bearing flowers of the same colour and shape as the geranium plant from which you started. Similarly, if a cutting is taken of a pink carnation, the resulting carnation plant will produce pink flowers just like the parent. In the same way by dividing the roots of a blue lupin we shall be sure of getting only blue lupins next year. As you can imagine, this process is most important to a nurseryman if he wants to be sure that what he advertises as a blue lupin plant will really produce blue flowers or that what he says in his catalogue is a giant kind of delphinium will really bear large flowers.

The important thing to remember about vegetative propagation is that it only takes *one* plant to make several new ones and that in every case the new plants are exactly like the parent plant. Thus, unlike sexual reproduction, the way in which plants are able to multiply by vegetative propagation, does not involve the union of male and female sex cells. Where one living thing can give rise to a new generation on its own in this way, the process is called *asexual reproduction*. Later on you will be learning about the ways in which plants can reproduce by sexual methods.

7.2 Can animals reproduce from pieces of themselves?

You will have seen from the experiments you have just done, that some plants are able to grow from bits of themselves. Indeed this kind of reproduction is quite usual throughout the plant kingdom. It is not nearly so common in animals.

Nevertheless, many simple forms of animal life consisting of one cell only, are able to reproduce themselves by dividing in two. One of the slightly larger forms which uses a similar process and which we can just see with the naked eye, is *Hydra*, a curious creature looking rather like a small sea anemone. Perhaps you saw one when studying Chapter 1 (see figure 4*d*).

7.21 The appearance and behaviour of *Hydra*

During the summer months try collecting water weeds from ponds or ditches and putting them in jam jars of pond water. After a day or so you may see several *Hydra* clinging to the sides of the jar. Their bodies are transparent and jelly-like and they have arms or tentacles like a sea anemone, usually about seven in number. *Hydra* is capable of extending its body. It clings to the jar with the base of its body, and stretches until it is nearly an inch long and its body becomes very thin (see figure 102). The ring of delicate tentacles also extends. If the jar is shaken, the *Hydra* will contract instantly into a small blob, at the same time drawing in its tentacles.

7.22 How *Hydra* feeds

In a pond *Hydra* feeds mostly on small crustaceans such as the water fleas *Daphnia* and *Cyclops* (see figure 103). Since both of these are very active animals while *Hydra* lives attached by its base to

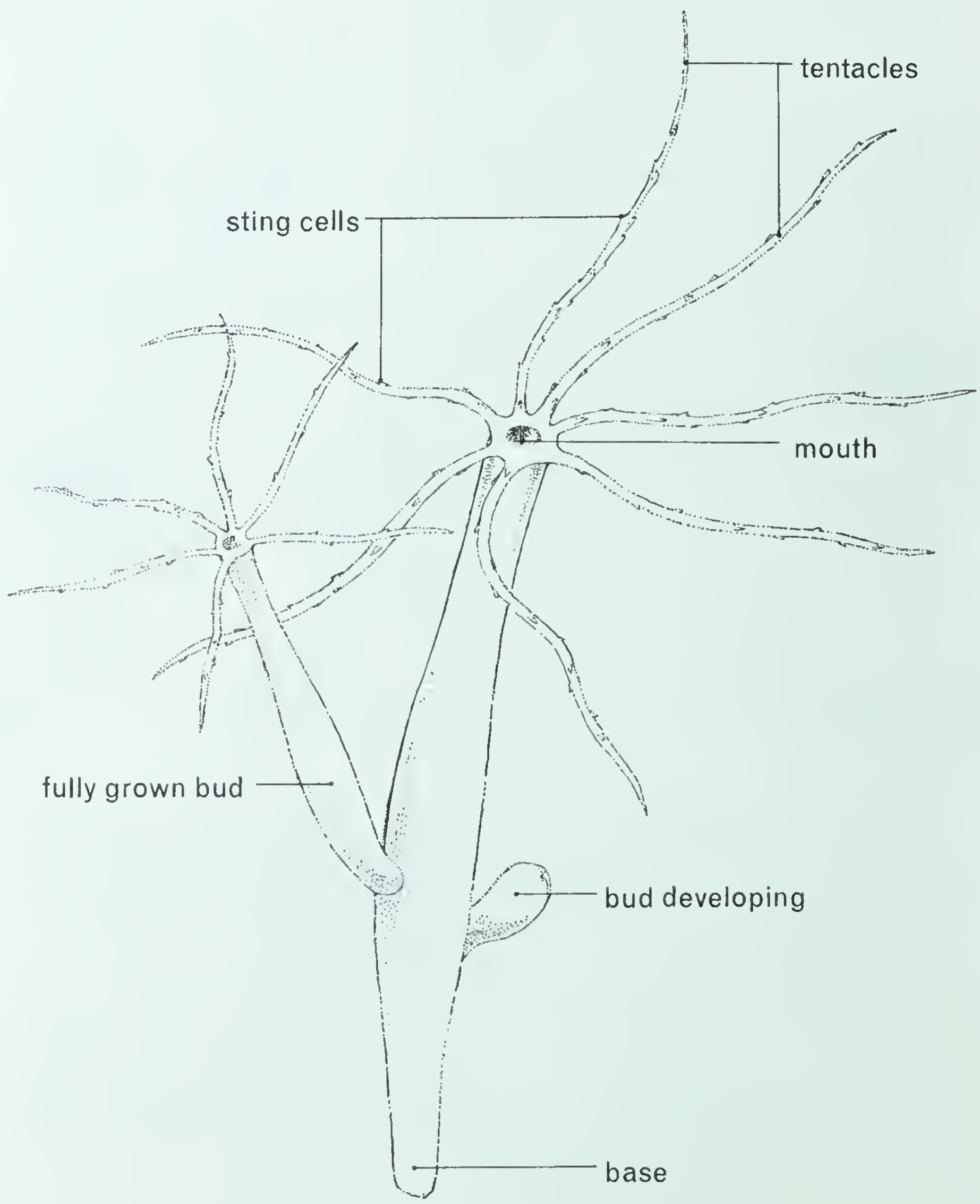
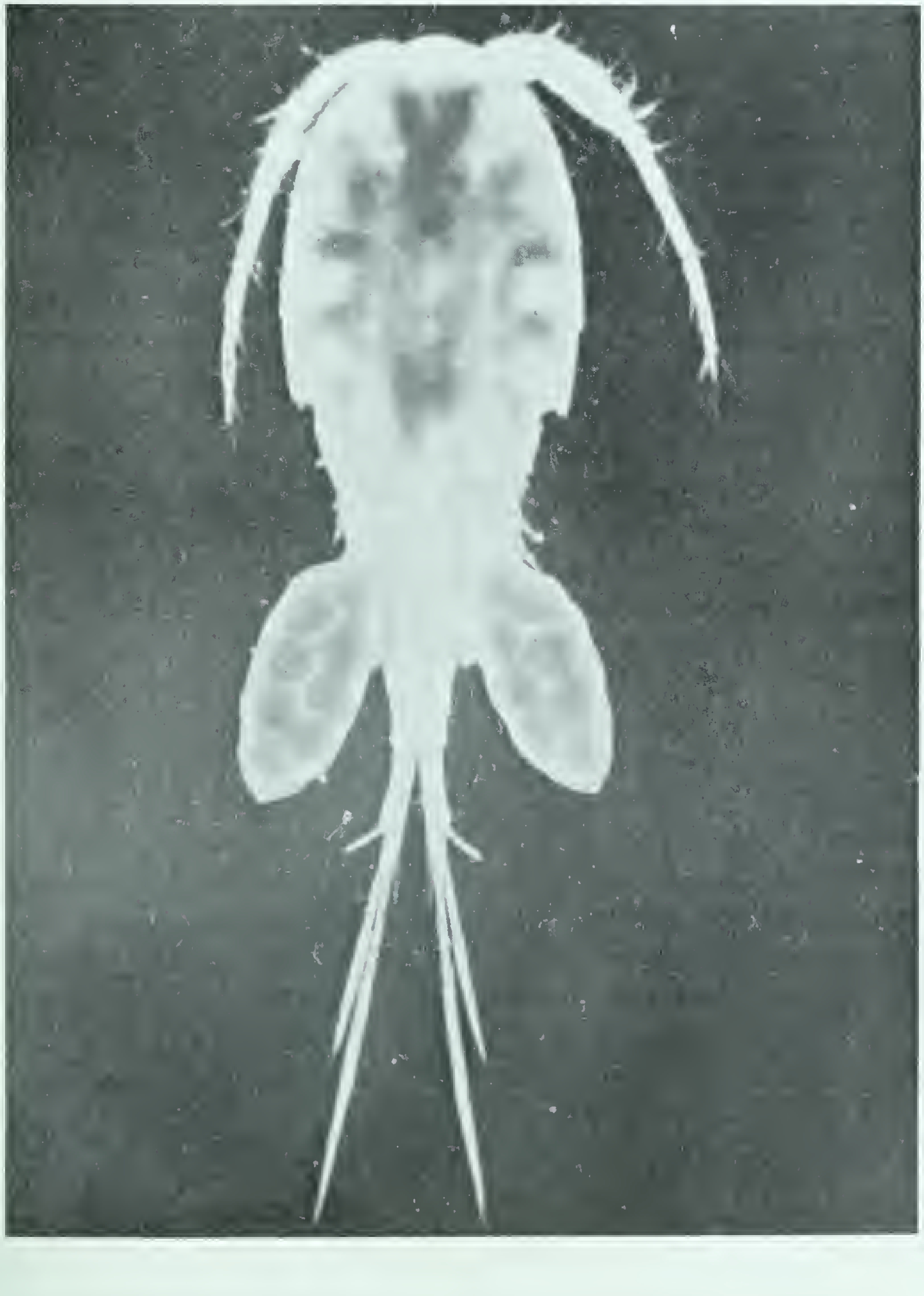


Figure 102
Hydra with buds. The body and tentacles are extended. The bud on the left is fully developed. Its base is constricted and it is nearly ready to drop off. The bud on the right has not yet developed tentacles.

a



b

Figure 103
The food of *Hydra*.

a. Water flea (*Daphnia*) × 30

b. *Cyclops* × 45

Both *Daphnia* and *Cyclops* swim by moving their antennae like oars in the water. You can just see them with the naked eye. *Photos by John Clegg.*

pondweed, it has to use special ways of catching and killing its prey. To do this the body becomes stretched and the tentacles are extended and wave about. Sooner or later, a small crustacean swims accidentally into the tentacles which immediately contract around it, drawing it towards the mouth. Along the tentacles are rows of sting cells, so small that you cannot see them without a lens. These produce a poison which paralyses the prey so that before it is drawn into the mouth it has ceased to struggle.

You may be able to watch all this happening if you have been lucky in finding *Hydra*. To do so, you will need to use a hand lens, or, better still, a low power binocular microscope.

7.23 *Hydra* grows buds

If *Hydra* is given plenty of food in the form of water fleas it will soon begin to form bulges on the side of the body. These bulges or buds grow quite quickly and develop tentacles until each looks like a miniature *Hydra*. The parent may produce two or three buds at the same time (see figure 102).

How many buds can you find on a living specimen or, failing that, on a permanent microscope preparation ?

This kind of reproduction – asexual reproduction – which really involves a single parent splitting off a part of itself, resembles closely the process in plants such as *Bryophyllum*. So long as the *Hydra* is well fed it will continue to reproduce asexually by budding.

7.24 Replacement of lost or damaged parts

We have seen that while small organisms such as bacteria can reproduce by dividing in two, larger and more complicated ones such as *Hydra* can only form buds. The body of the parent itself cannot divide. In general, the further we go up the animal kingdom the more complex do organisms become and the less they are able to multiply in this way.

Starfish which live in the sea normally have five arms (see figure 104*a*). They cannot multiply by dividing or budding, but if an arm becomes accidentally broken off, a new one will grow in its place. Sometimes you can find starfish with one or more new arms in the process of growing (see figure 104*b*). The ability to replace lost or damaged parts only (not new individuals) is known as *regeneration*. In the most complex organisms such as man, the power of regeneration is very limited. If we lose a leg, unlike the starfish, we cannot grow another. In us, regeneration is limited to the growing of such structures as finger nails or new skin over a wound.

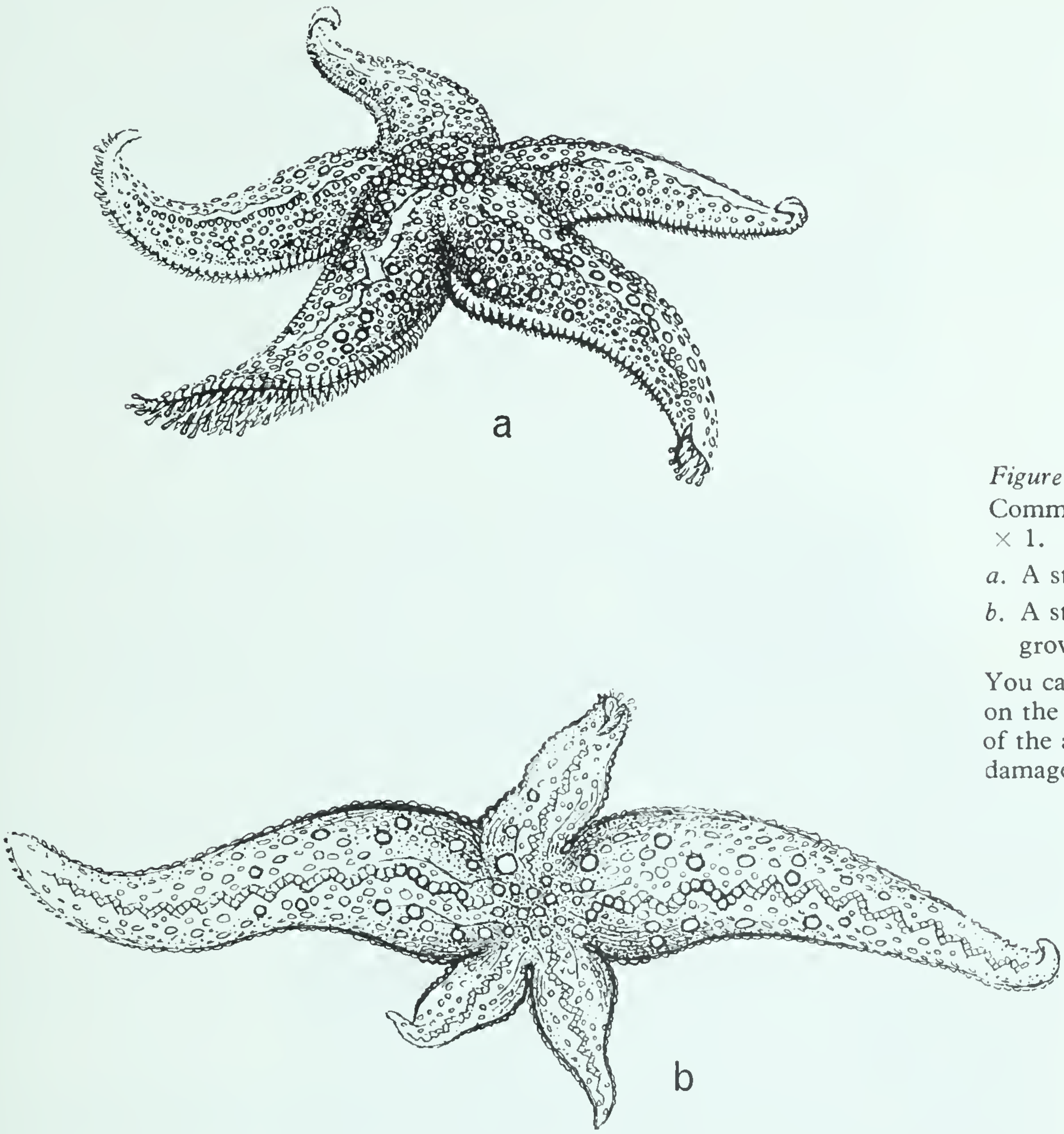


Figure 104
Common starfish (*Asterias rubens*) × 1.

a. A starfish with five arms.

b. A starfish with three new arms growing.

You can often find this starfish on the seashore at low tide. Three of the arms in (*b*) have been damaged and are growing again.

Summary

Many kinds of plants and some simple forms of animals are able to reproduce from pieces broken off themselves which grow into new individuals. Each of these new individuals is exactly like the parent; but there is only one parent. This kind of multiplication is called *asexual reproduction*.

Finding out about locusts

8.1 What are insects?

In Chapter 1 you classified a number of different kinds of animals and plants into groups or phyla. The largest of these was the phylum Arthropoda to which the insects belong. Look again at figure 3 which shows that there are more insects in the world than all the other animals put together. The class Insecta already includes about 722,000 species of insects, and many more are being discovered and named every year.

Now look at table 7, Chapter 1, which gives the characteristics of each of the four classes of Arthropoda. From this table you will see that insects are distinguished from other arthropods by the fact that their body is divided into three parts (head, thorax, and abdomen) and that they have three pairs of legs, usually two pairs of wings and one pair of antennae. But we shall be able to find out a lot more about them than this.

Insects are to be found everywhere, and so many of them are easy to keep that it may be difficult to decide which kinds to choose for studying in the laboratory. Probably it will be best to select a fairly large insect with an interesting life history to begin with. Grasshoppers are large and easy to rear but they are difficult to breed in captivity. But the locust, which is a large kind of grasshopper not found in this country, breeds well in the laboratory.

8.2 Locusts

There are several different kinds of locusts but the best species for keeping in school is the African migratory locust (*Locusta migratoria migratorioides*) which is found in the tropical regions of Africa as well as in European countries bordering the Mediterranean. This species is found in huge swarms in different parts of Africa and flies from place to place eating and completely destroying all kinds of vegetation, including valuable crops. So important are locusts because of the destruction they cause, that in Africa special precautions have to be taken to keep them under control.

8.3 Keeping locusts in the laboratory

Cages

A suitable cage for keeping locusts can be made of either metal or wood and should be 20 inches high and 15 inches square (see figure 105). A false floor, 4 inches above the real floor, has three holes just large enough to take $4 \times 1\frac{1}{2}$ inch test-tubes filled with sand in which the locusts will lay their eggs. Plenty of ventilation should be provided by cutting a round hole in the roof of the cage 6 inches in diameter and covering it with perforated zinc. There should also be a small door in the roof so that you can get your arm inside to change the food and clean out the cage.

Figure 105
A cage for locusts. *Photo by Alan Gentle.*

In a cage like this you can rear up to 100 locusts at a time.

Temperature

Locusts live in hot climates so the cage must be heated. This is best done with an electric light bulb fitted in the back of the cage and another at the back beneath the false floor. With a 60 W bulb in the top and a 25 W bulb in the bottom, the cage can be kept at a temperature of about 34°C during the day. By switching off one of the bulbs at night the temperature should fall to about 28°C. These are the conditions in which the locusts will develop best. To record the temperature of the cage you will need to hang a thermometer inside.

Food

Locusts will eat a variety of vegetable foods but they prefer a plentiful supply of fresh, but not wet, green grass each day. They should also be given a dish of dry wheat bran. If the grass is fresh they will not need any water but will obtain all the moisture they require from the grass. In winter, when grass is scarce, they can be fed on chopped raw carrot, tomatoes, or cabbage leaves, as well as bran.

Perches

The adult locusts like to climb and so you will need to provide some twigs in the cage. For the young locusts which are called nymphs, twigs are essential. If you have any nymphs in a cage try to find out by watching them why this is so.

Routine care

Every day you should clean out any old grass and locust droppings and put a fresh supply of grass in the cage. These operations can be done through the feeding door. The amount you give will depend on the number of locusts, but there should always be enough to last from one day to the next. Be careful to put in the bundle of grass *behind the twigs and away from* the electric light bulb, otherwise the grass could possibly catch fire if it gets too dry. Also add a fresh supply of bran to the dish.

8.4 How is the body of the locust constructed?

In order to understand how a locust uses its body for feeding and moving about we must find out how the parts of the body are put together. Look at a preserved specimen of an adult locust.

1. With the help of figure 106 find the different parts of the locust's body – its head, thorax, abdomen, three pairs of legs, and two pairs of wings.
2. Now look more carefully at the way in which the wings and legs are joined onto the body. Find the first, second, and third segments of the thorax. To which parts of the thorax are (*a*) the fore wings and hind wings attached, and (*b*) the first, second, and third pair of legs?

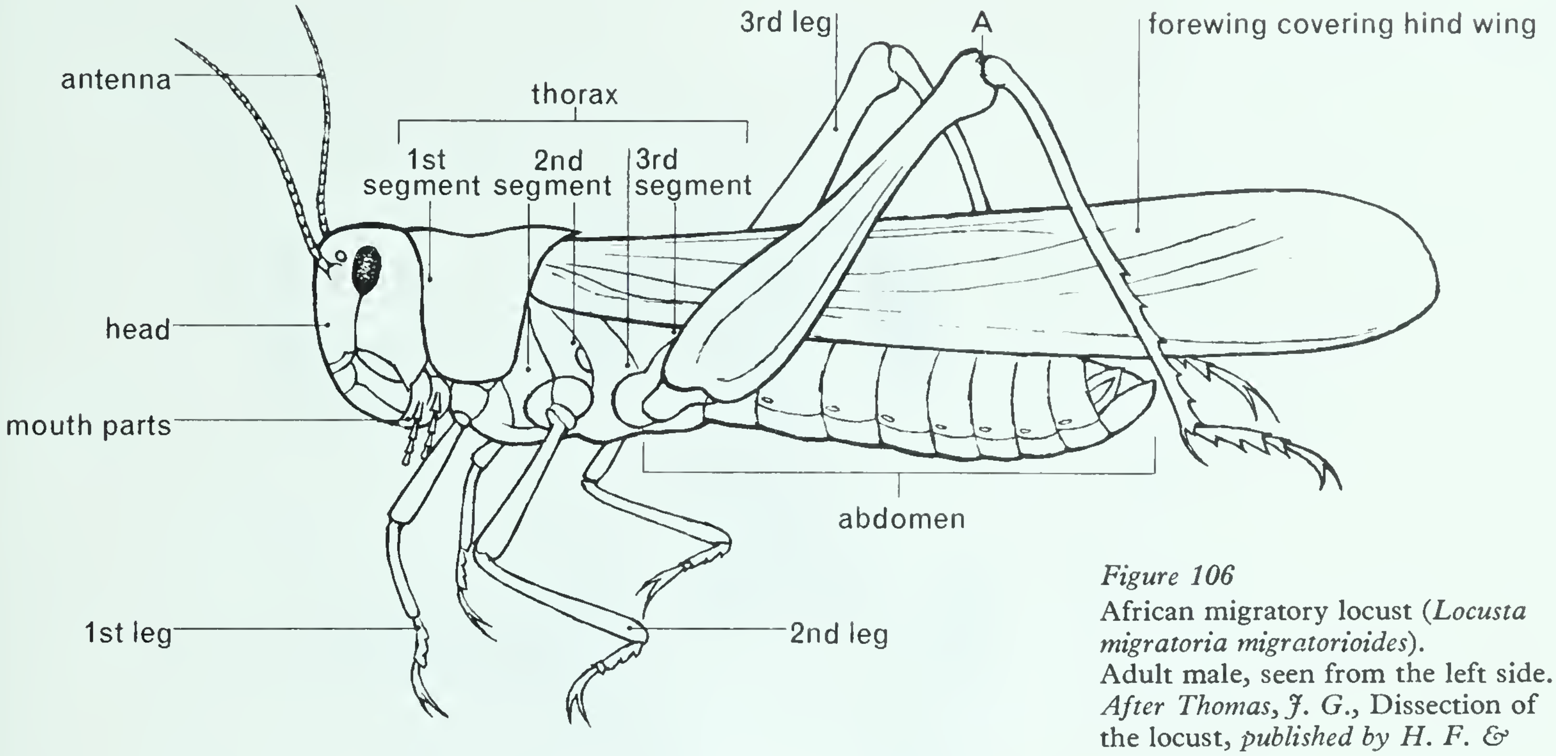


Figure 106
African migratory locust (*Locusta migratoria migratorioides*).
Adult male, seen from the left side.
After Thomas, J. G., Dissection of the locust, *published by H. F. & G. Witherby Ltd.*

What do you notice about the structure of the third pair of legs?

3. Figure 107 shows an enlarged drawing of the head of the locust seen from the front. Hold your locust so that you are looking at it from the same position. Using a lens, can you see that the eyes are really made up of numerous small eyes and are therefore called 'compound eyes'? Are the eyes nearer the top of the head than the bottom? Do they occupy more or less than half of the area at the side of the head?

4. Still looking at the head from the front, find the upper lip or *labrum.* Very carefully lift the labrum up with a blunt seeker and find the pair of strong jaws or *mandibles* beneath. Figure 108 shows the mandibles in position and Figure 109 one of the mandibles dissected out complete with its strong muscles. Notice also the jointed palps visible on either side of the labrum.

5. Figure 110 shows one of the hind legs enlarged. On your specimen find the various parts of the leg – *femur*, *tibia*, and *tarsus.* Figure 111 shows the tarsus enlarged. With a hand lens find the soft pads (called plantulae) on the underside of each tarsal joint and the pad between the claws at the end of the tarsus (called the arolium). Find the large spines on the end of the tibia.

6. Hold the locust by its wings between your finger and thumb. Are the femur and tarsus hard? What other parts of the body are hard? Now gently bend the third leg at A (see figure 110). Is there a soft skin between the joints of the body?

8.41 Finding out about how locusts use their bodies

By watching locusts we can find out many interesting things about their habits and how they use their bodies – how they feed and move.

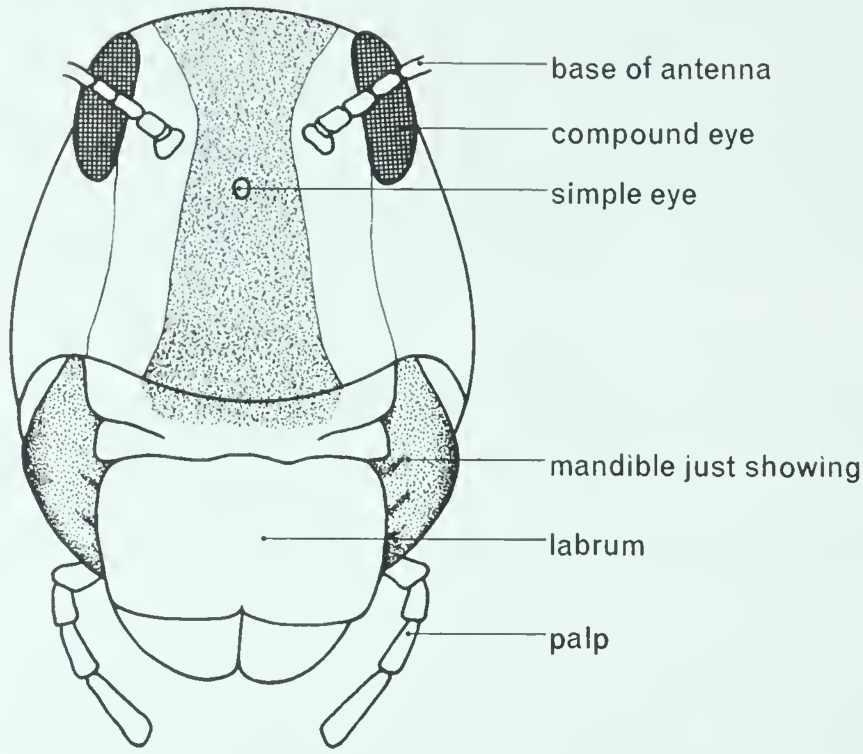


Figure 107
Head of a locust seen from the front.

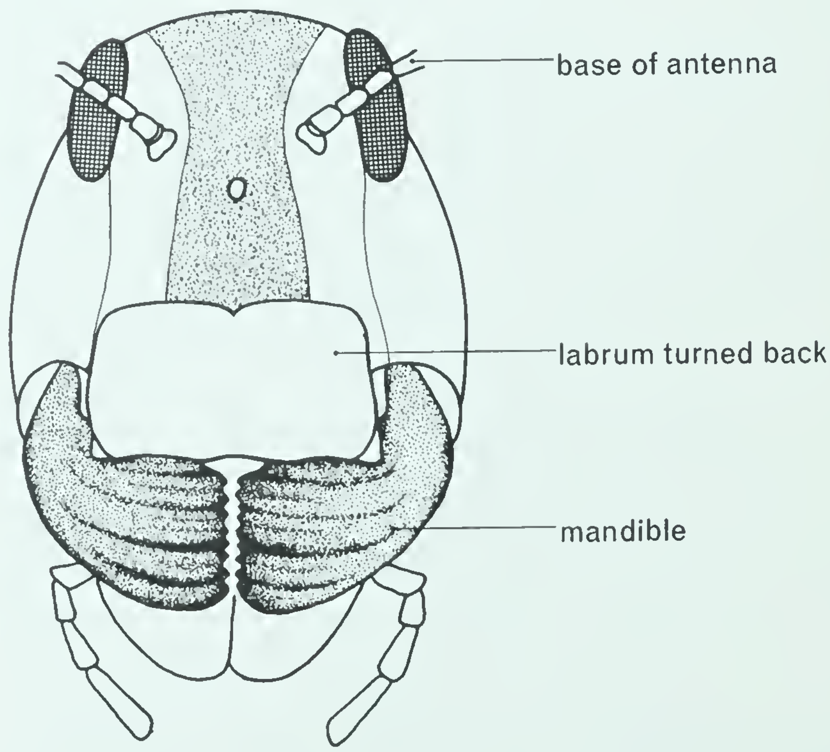


Figure 108
Head of a locust with the labrum turned back to show the mandibles. The cutting edges of each mandible meet in the centre.

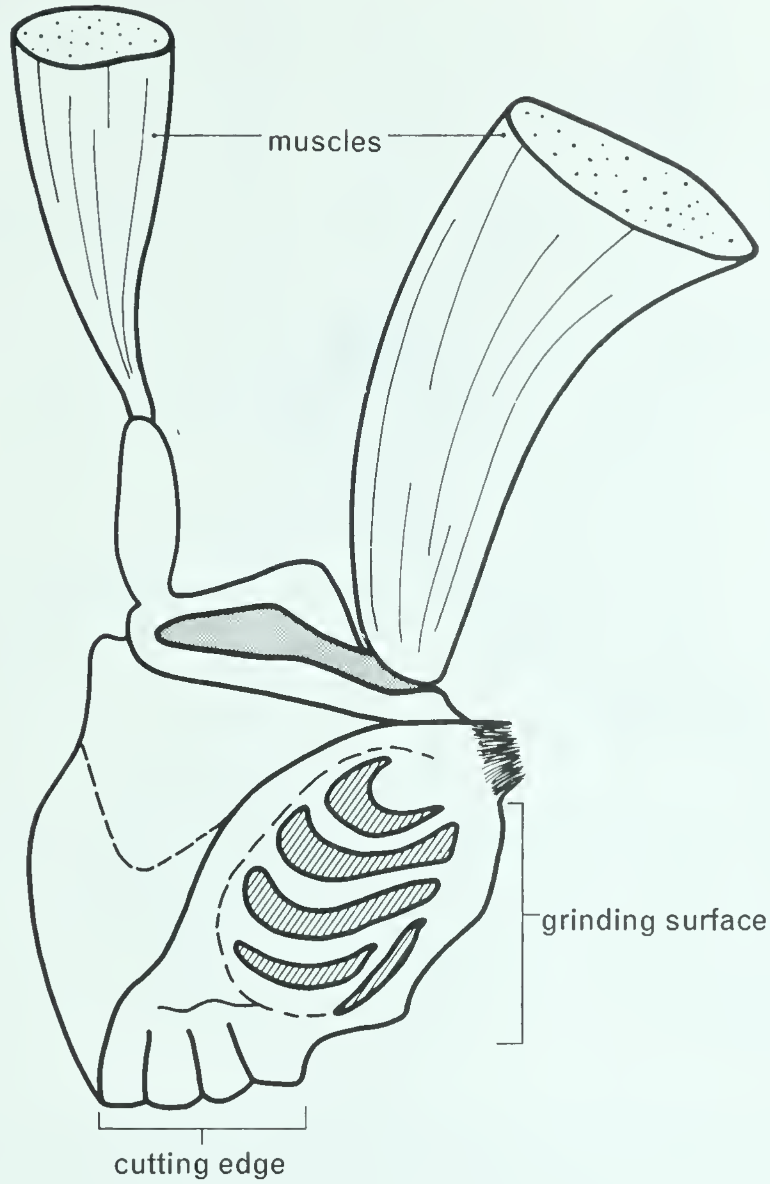


Figure 109
Left mandible of a locust.
Note the strong muscles which move the mandible during feeding.
The inner surface is ridged for grinding the food.

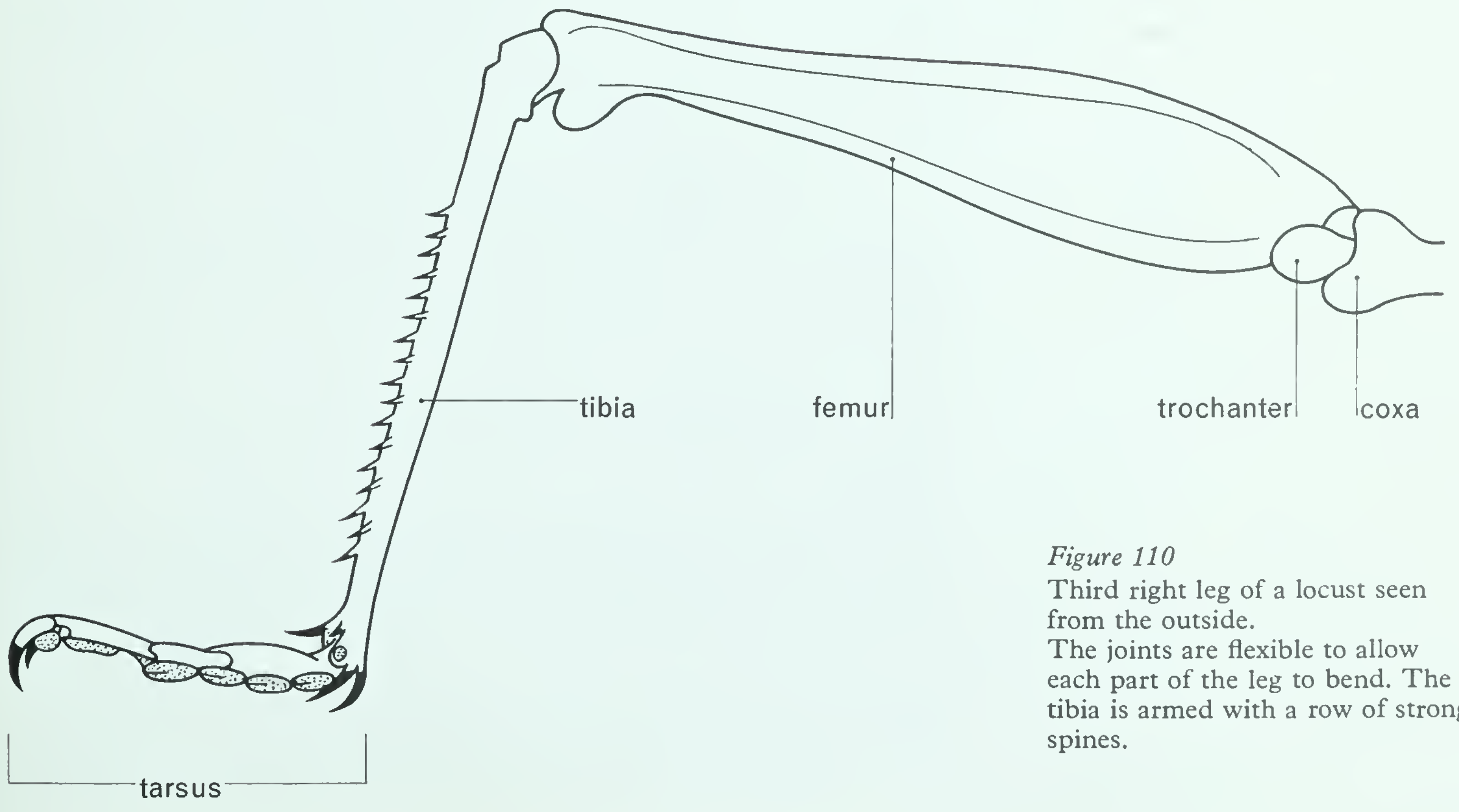


Figure 110
Third right leg of a locust seen from the outside.
The joints are flexible to allow each part of the leg to bend. The tibia is armed with a row of strong spines.

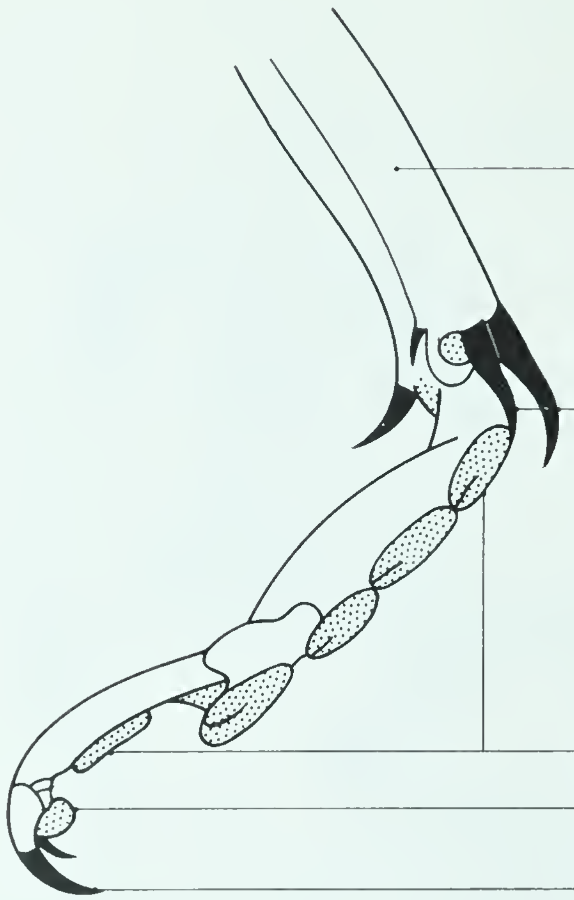


Figure 111
Tarsus of the third leg of a locust, much enlarged.
The plantulae are soft pads on the underside of each tarsal joint.
After Thomas, J. G., Dissection of the locust, *published by H. F. & G. Witherby Ltd.*

Watch the locusts in the cage and as you do so try to answer these questions:

1. How does the locust grasp a blade of grass while it feeds?
2. How do the labrum and jaws move as it is feeding?
3. Are any other parts of the body moving while it is feeding?
4. You found out in section 8.4 that much of the body of the locust is covered by a hard jointed skeleton. Can you see the reason now for the thin membranes between the joints?
5. If any locusts are walking up the sides of the cage can you see how they cling onto the cage? (See figure 111.)
6. How do the locusts use their feet for clinging onto twigs or grass?
7. Open the lid of the cage and put your hand in. The locusts will start flying round the cage. Can you see how they use their back legs and wings?

8.5 The life history of the locust

Mating

In a cage of adult locusts there will probably be both males and females. You can tell the difference between them because the males turn yellow and brown a week or so after they emerge as adults. The females have no yellow on their bodies and are usually larger.

If there are males and females they will often be seen together in pairs, the male on top of the female. When they are in this position they are mating and may stay together for several hours. Look more

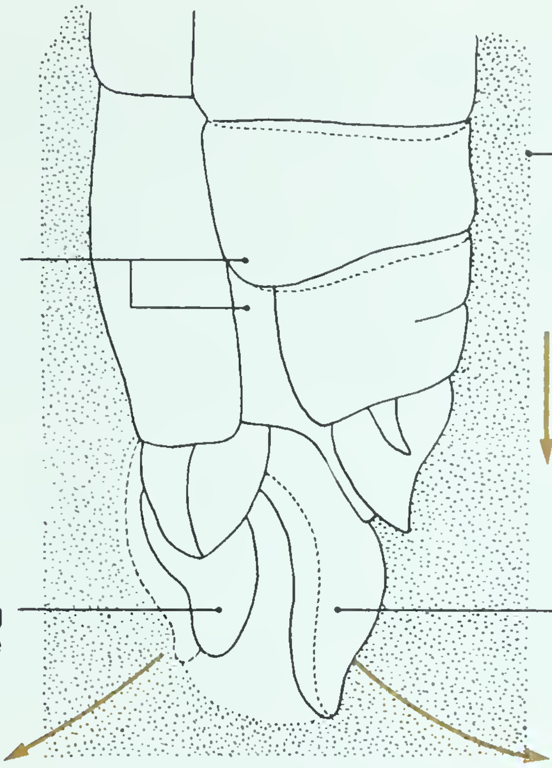


Figure 112
End of the abdomen of a female locust pushing through sand.

closely at a pair of locusts mating and you will probably see that the male has curved the end of his abdomen so that it is touching the end of the female's abdomen. The female is receiving sperms from the male which will fertilize the eggs inside her body as she lays them.

Egg-laying

In the desert regions of Africa, where locusts are usually found, the females lay their eggs in the warm, damp sand after the rainy season. In the laboratory we must try to copy these conditions if we want the locusts to lay.

Under natural conditions, locusts lay their eggs in the desert sand after it has rained and when the sand is still damp. Thus the tubes in the front of the cage should be filled with clean, moist sand. The sand should be kept damp by adding distilled water every day, to each tube. This is best done with a 5 cm^3 syringe.

Sooner or later you are bound to see one of the females sitting on top of one of the tubes, often with a male locust still on her back. Watch carefully and try to make out what she is doing. If you are lucky you will be able to see the female's abdomen pushing down through the sand. The valves at the end of the abdomen (see figure 112) are opening and closing and as they do so they are pressing the particles of sand apart. In this way the whole abdomen is pushed further and further through the sand, getting longer and longer as it does so, until it very nearly reaches the bottom of the tube. Then the female will start to withdraw the abdomen and as she does so, she fills the hole in the sand with a frothy substance in which she lays her eggs.

By the time the female locust has almost withdrawn her abdomen, the column of froth will be packed with eggs. The froth hardens round the eggs and the whole structure is called an egg pod.

The young locusts hatch and develop

If you are lucky you may see the young locusts actually coming up out of the sand in the egg tubes. They are a pale colour and will probably stay on top of the tube for a while. During this time they become darker in colour and soon start to hop about.

At this stage they are called 'hoppers', and they will soon begin feeding. Thus you should provide grass and a dish of bran in each of the cages. They will also need a few twigs to climb.

You may have found, in section 8.4, that the locust, like all other insects, is covered with a hard skeleton which will not stretch, so when the hoppers feed they cannot get any bigger unless they change their skins. If you watch the hoppers carefully, you may see one or two of them climbing up the twigs in the cage and grasping a twig with their feet. As they hang head downwards the skin splits along the back of the hopper and a new nymph emerges. This skin splitting or moulting is called *ecdysis*. (Greek, *ekduein* = to shed.)

At first the newly emerged nymph is pale in colour and quite soft, but the skin later hardens and becomes darker. The nymphs will soon start to feed again and, of course, to grow so that once more they must go through an ecdysis. Each nymph stage between one ecdysis and the next is called an *instar*. When the hoppers are newly hatched they are called first instars. In the locust the nymphs pass through five instars before they finally emerge as adults (see figure 115).

8.51 Examining an egg pod

Every day you should check the glass tubes filled with sand to see if they contain one or more egg pods. If an egg pod has been laid against the side of the tube you will be able to see it through the glass. If you cannot see anything, carefully scrape away the loose sand at the top of the glass tube. If an egg pod has been laid, the top of it will show as a hard lump in the sand.

You can easily examine an egg pod and find out more about the eggs inside it.

1. Empty out the sand from one of the glass tubes and take out the egg pod made by the locust.
2. Measure its length in millimetres.
3. With a pair of sharp pointed scissors carefully slit the egg pod up one side without damaging the eggs inside.
4. Draw what you see.
5. With a blunt seeker carefully separate the eggs from the sand and froth and count them.
6. With a hand lens examine one of the eggs and measure its length in millimetres. Figure 113 shows what you should look for.

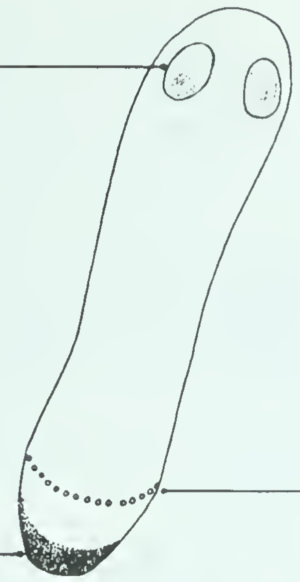


Figure 113
The egg of a locust.

b. Why does she start to lay her eggs at the bottom of the tube?
c. Can you think of several reasons why the female surrounds her her eggs with froth?
d. How are the eggs arranged in the egg tube?

8.52 Does temperature affect the length of incubation of the eggs?

Under natural conditions in the desert, the temperature of the sand in which the female locusts lay their eggs is usually about 34°C. At this temperature the eggs take eleven days to hatch. You could try keeping one egg pod at 34°C, the best or *optimum* temperature, and one pod at a lower temperature. In this way you could find out if eggs kept at a lower temperature take longer to hatch.

1. Use two of the glass tubes in which there are freshly laid egg pods. Label one 'A' and the other 'B', adding to the labels the date on which they were laid.
2. Add 5 cm^3 distilled water by means of a dropper or syringe to each tube and cover the tube with a lid taken from a meat paste bottle, to keep the sand moist. As you have learnt, the female locusts always lay their eggs in damp sand. Can you think of a reason for this?
3. Leave tube A in the big locust cage at 34°C. This will be your 'control'. Put B in an incubator at 28°C.
4. You will expect the eggs in the control tube A to hatch about 11 days after they were laid. So you must remember to watch for signs of the young locusts hatching in both the tubes from the eleventh day onwards.
5. Make a note of the date on which the young locusts hatch in tubes A and B. Did the eggs in tube B take longer to hatch than in A? If so, can you give a reason?

8.53 What does an embryo locust look like?

In the course of her life a female locust will make several egg pods, each containing anything from between 30 and 100 eggs about the size of a grain of rice. Inside each fertile egg a young locust nymph is developing.

Look at the specially prepared egg under the microscope. Can you make out the head, abdomen, and legs of the future locust nymph? In what ways is it different from the embryo chick?

8.54 Does temperature affect the rate at which the nymphs develop?

In the case of the locust eggs you will probably have found that by keeping the eggs in tube B at a lower temperature, they took longer to hatch than those in tube A which were kept at 34°C. In Chapter 5 you incubated hens' eggs at 38°C (the optimum temperature for incubating hens' eggs). If you had tried incubating another batch at a lower temperature, you might have found that, like the locust eggs, they took longer to hatch. In other words, temperature affects the length of incubation. But we could say equally well that the rate of development of the embryo inside the egg is affected by temperature. We must not forget, however, that there may well be other things, besides temperature, which affect their development.

By keeping two batches of nymphs in separate cages at different temperatures you test the effect of one factor – temperature – on their rate of development. But you must ensure that, as far as possible, the other factors are the same for each batch – particularly living space and amount of food.

The apparatus you will need consists of two Perspex cylinders like the one in figure 114. Each cylinder rests on perforated zinc covering a hole in a biscuit tin fitted with an electric light bulb. This heats the air in the biscuit tin and the heat passes up into the cylinder cage which has a lid of perforated zinc. The cage is also fitted with a thermostat, by means of which the temperature of the air inside can be controlled. We can keep Cage 1 at the optimum temperature of 34°C and Cage 2 at a lower temperature, say at 28°C.

1. Transfer 20 newly hatched hoppers to Cage 1 and 20 to Cage 2.
2. Record the date on which these newly hatched hoppers (first instars) change their skins and become second instars. You will find a problem here, since the hoppers probably will not all change from one instar to the next at exactly the same moment and so you will have to decide to look at the cages each day at the same time. When *half* the hoppers have changed to the next instar, record the date. Some of the hoppers in the two cages will probably die and so this method of deciding when to record the date of the next instar will be fair.

Figure 115 shows all the instars and the features you should look for when deciding whether they have changed from one instar to

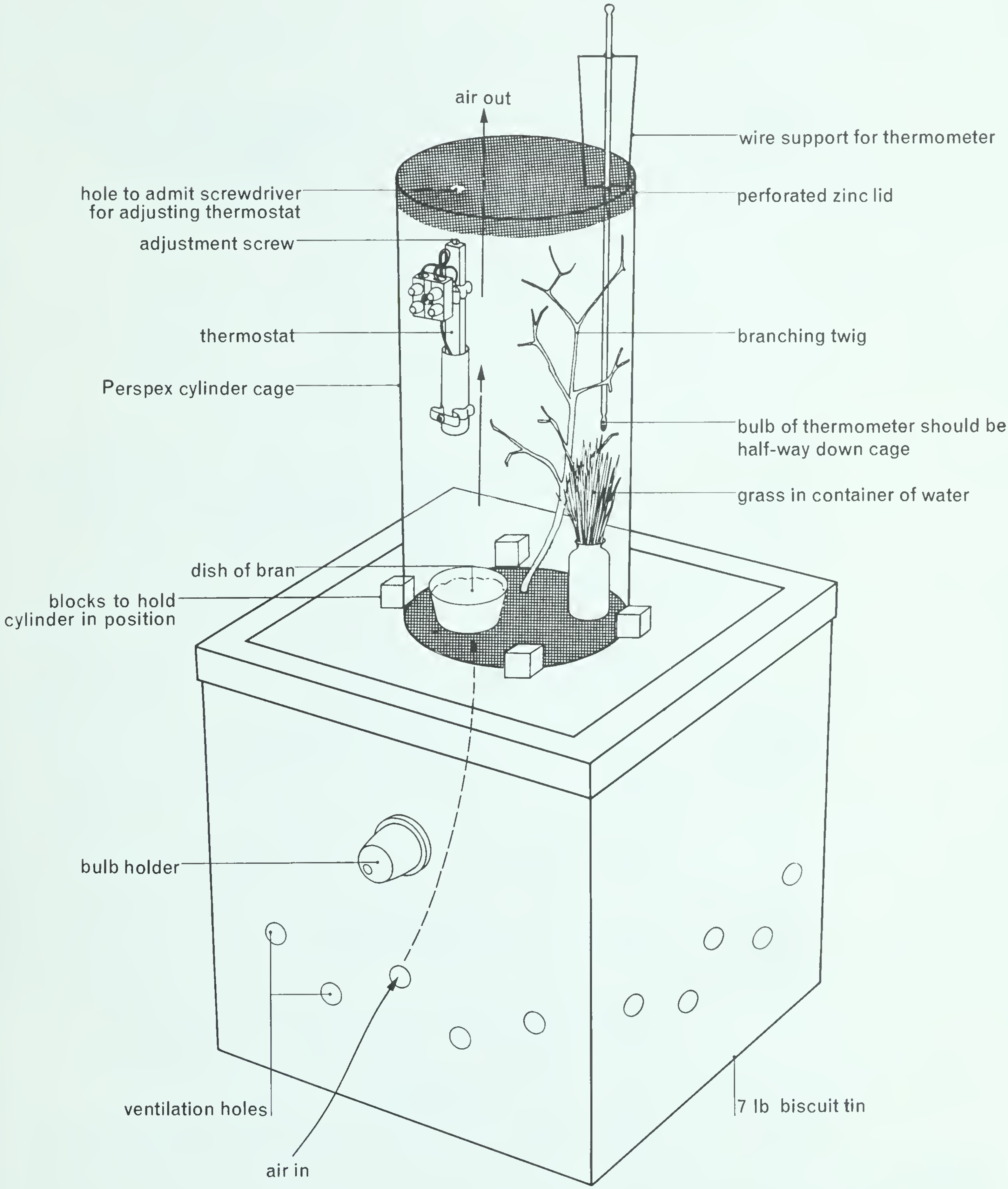


Figure 114
Apparatus for comparing the rate of growth of locust nymphs.

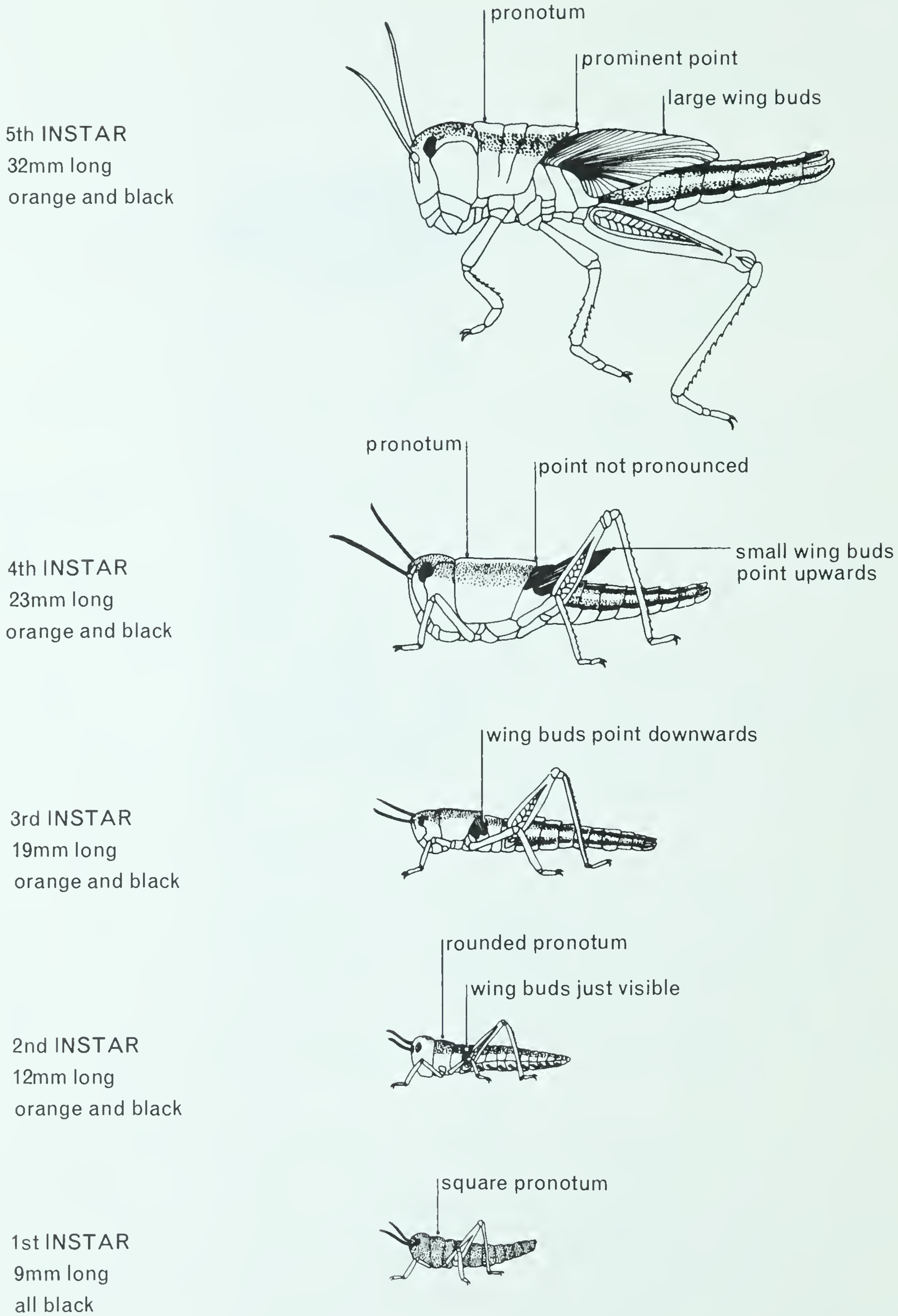


Figure 115
The development of the locust. The labelling indicates the characteristics you should look for to distinguish the nymphs. The size of a nymph is not always a reliable guide.

the next. The first three instars are rather difficult to tell apart, and you will probably need help in distinguishing them.

3. It will take several weeks for the nymphs to grow into adults and thus during the next few weeks you will be making records of their progress. To help you do this you should prepare a table for your records like the one below:

Date when eggs hatched...

	Date when half the nymphs changed to the next instar	Notes on the appearance of the nymphs
2nd instars emerged		
3rd instars emerged		
4th instars emerged		
5th instars emerged		
Adults emerged		

4. While the locust nymphs are growing, watch them from time to time and make notes in the last column of your table of what they look like.

Look at the notes in your table of results and try to answer these questions. (You may have to use a hand lens to find the answer to some of them.)

a. Why do the nymphs climb up a twig before they moult?

b. How do the nymphs hold onto the twig while they are moulting?

c. Did you notice any difference in the colour of the five nymphal instars?

d. Which instar first shows the developing wings (wing buds)?

e. Is there any difference in the *position* of the wing buds in the third and fourth instars?

f. Is there any difference in the general colour of the nymphs kept in the large cage and nymphs of the same stage kept in the small Perspex cages?

g. Make a list of the differences you observe between the fifth instar nymph and the adult. What do you notice about the wings of the adult compared with those of a fifth instar nymph?

Making a graph of your results

Cage 1, kept at 34°C, is the control for the experiment, since this is the temperature at which the nymphs live under natural conditions.

From your table of results you can now construct a graph to show more clearly what effect rearing nymphs in Cage 2 at the lower temperature of 28°C has had on their rate of development. Your graph may look something like figure 116.

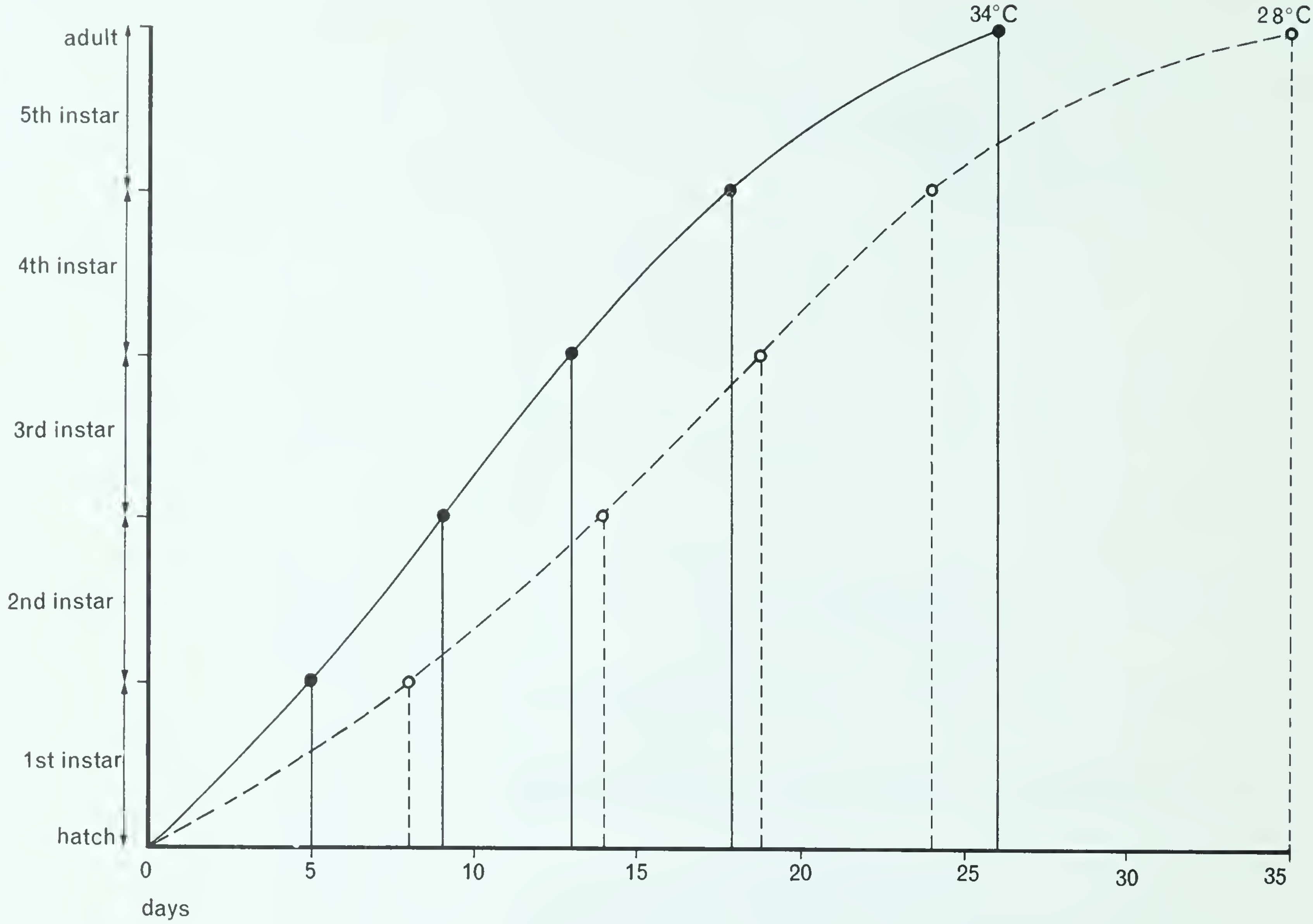


Figure 116
The effect of temperature on rate of development in the African migratory locust (*Locusta migratoria migratorioides*).

Look at the graph you have made and try to answer these questions:

a. Biologists experimenting on locusts have found that if they are kept at 34°C, the duration of each of the instars is as follows:

1st instar = 5 days		
2nd instar = 4 days	}	making a total of 26 days from
3rd instar = 4 days		the time of hatching until the
4th instar = 5 days		final moult to the adult stage.
5th instar = 8 days		

How does your record of growth for the locust nymphs kept in Cage 1 compare with this? Did they take more time or less time to develop?

b. How long did the nymphs in Cage 2 take to develop from the day of hatching until the final moult to become adults?

c. When you have drawn the vertical lines down from the end of each instar on your graph, you will be able to compare the number of days each instar lasted in Cage 1 and Cage 2. Was there any period during the development of the nymphs in Cage 2 at the

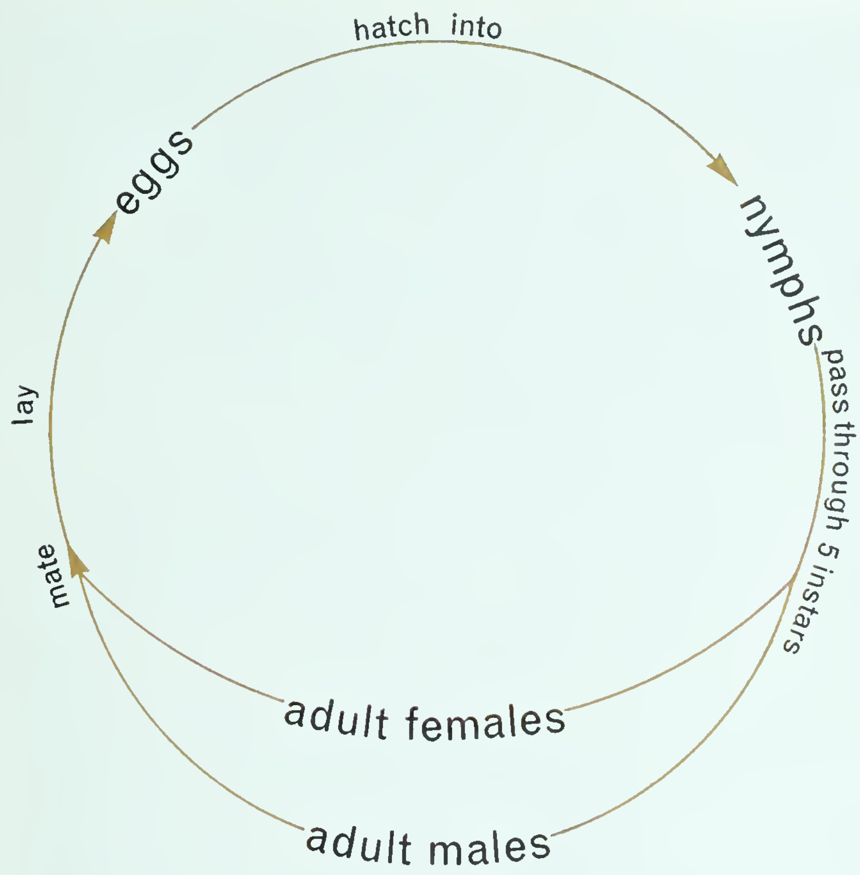


Figure 117
The life cycle of the locust.

lower temperature, which was longer than that of your control group?

Now you have observed the effect of temperature on the growth of the nymphs, can you think of any ways in which temperature is likely to affect the adult locusts?

No doubt you have not only been making records of the growth of the nymphs, but studying the life history of the locust at the same time. Figure 117 shows the life cycle of the locust in the form of a diagram.

8.6 Other factors affecting growth

You have been investigating the effect of temperatures on locusts and you may have been able to think of several ways in which warmth has an effect on the adults as well as the nymphs. If you switch off the lights in the cage so that the temperature falls you may find that they do not eat so much food or move about the cage so quickly. Perhaps you will not notice so many pairs of adults mating or so many females laying eggs. All animals – including ourselves – are affected throughout our lives by a number of things – whether it is hot or cold, dry or wet, whether there is a plentiful supply of food, or whether food is scarce. You can probably think of other factors like these for yourselves.

In the last experiment you tested the effect of one factor only – temperature – on the locust nymphs. By keeping one batch of nymphs (the control) at one temperature and another at a lower temperature, you were able to compare their rates of development. Each batch was given a plentiful supply of food and was kept in a cage of the same size. In fact, so far as was possible, the living conditions for each batch were the same except for the one factor, temperature.

This is the proper way of setting about any scientific investigation of this kind. If you are going to examine the effects of one factor, you must vary that factor alone, keeping the others as constant as you can.

8.7 Ways of measuring growth

In section 8.54 you measured the rate of growth of the locust nymphs by noting the number of days they took to change from one instar to the next. Can you think of any other ways in which you might measure their growth? Would it be possible, for instance, to measure the length of the nymphs at each instar? Would it be right to measure just one nymph or should you measure several and take the average of their lengths? Would it matter when you measured them during the period of a particular instar? (Before you answer this, look at section 8.54.)

Could you measure the growth of nymphs by weighing them? If so, how would you set about doing it?

Summary

Locusts show the following characteristics which are typical of insects:

1. Their bodies are divided into three distinct parts – head, thorax, and abdomen.

2. They have three pairs of legs, two pairs of wings, and one pair of antennae.

Locusts pass through three stages in their life history – egg, nymph, and adult, changing gradually from one stage to the next.

In the deserts of Africa the locust takes only twenty-six days to grow into an adult. By keeping locusts at their natural temperature of 34°C we can rear them in the laboratory in the same length of time, but if the temperature is lower they take longer to develop. Thus temperature has an important effect on the rate of growth. There are other factors which also affect growth.

Background reading

A plague of locusts

The sandy soil bordering the desert is warm and moist, for the rainy season has just finished. Pushing through the surface of the ground are numbers of newly hatched locusts. It is morning and the sun is just coming up. As they emerge the young locust hoppers are joined by others, until there are thousands upon thousands basking in the sun, their black and orange bodies forming a dense patch of colour.

Figure 118
A swarm of locusts flying over Ethiopia. *Photo, C. Ashall, by permission of the Anti-Locust Research Centre.*

Soon some of the hoppers start to move off. Others follow until a vast marching army is formed, all proceeding in the same direction. They are destined to go on marching for most of the day, stopping now and then to browse on the plants along their route. At sunset they leave the ground and climb up grass stems or low bushes where it is warmer.

Next morning the hoppers descend to the ground once more to bask in the sun, absorbing the heat of its rays which makes them active and restless to be on their way. They are growing larger and day after day the tightly packed army, its members jostling one with another, moves on.

Soon the young locusts change their skins for the last time and become winged adults. For a time they remain on the ground, turning round as the sun rises in the sky, so that their bodies can absorb its heat. By mid-day the locusts are becoming restless and active. Several of them may take to the air in clumsy flight, soon to be joined by the whole huge company. Carried along in the direction of the wind, the vast unending cloud blackens the sky, turning day into night. Every now and then the swarm settles down on the ground to feed, eating every scrap of vegetation it can find and leaving behind it nothing but the naked stalks of what had been a field of lush green maize or a rich crop of cotton.

At night the locusts settle on trees or bushes, descending to the ground once more as the sun comes up, to warm themselves and fly off to feed elsewhere.

Mating takes place on the ground. The female locusts test the soil to see if it is sufficiently moist and of the right texture, before they bore into it with their abdomens and lay their eggs. Thousands of females make their egg pods in the soil, all close together, and within a few days the young hoppers hatch. A new generation has begun once more.

This is the story of the African migratory locust (*Locusta migratoria migratorioides*) which can certainly be considered one of the oldest enemies of man, for tales of locust plagues are reported in the Old Testament.

An account of a swarm passing over the Red Sea, was described in the log of an old sea captain:

'For over five days the ship was passing through flying locusts. Her decks were overlaid with corpses of the insects many inches thick merely because they had collided with the rigging. It occupied two men's time all that while to sweep them off into the sea. The waves as far as eye could see were white with outspread wings of dead locusts as if the sea were covered with snow.

'Such multitudes of them were drowned that where waves washed them ashore banks of them were formed over three feet high for miles along the coast. The stench of the dead was unbearable and was perceived in villages far inland.'

A swarm of locusts such as this must be a terrifying sight indeed. Figure 118 shows a photograph of a swarm, 400 square miles in extent, flying over the dry grasslands of Ethiopia.

Once a swarm has reached such proportions man can only stand by and watch his crops invaded and destroyed. Nevertheless, some kind of counter action is needed, and the most helpless stage in the locusts' life is clearly when they are just hatching as hoppers from the egg pods in the ground. Nowadays, thousands of people in the African and Indian continents, as well as in other hot countries, are employed to watch for signs of hoppers appearing. Aircraft, equipped with special sprays, can be summoned by radio telephone, to any suspected area. Flying low over the ground they release their spray of insecticide which kills the hoppers. Inevitably some will survive and equally inevitably some bands of marching hoppers will escape detection altogether and will be able to give rise to fresh plagues.

Finding out about other insects

9.1 The large white butterfly (*Pieris brassicae*)

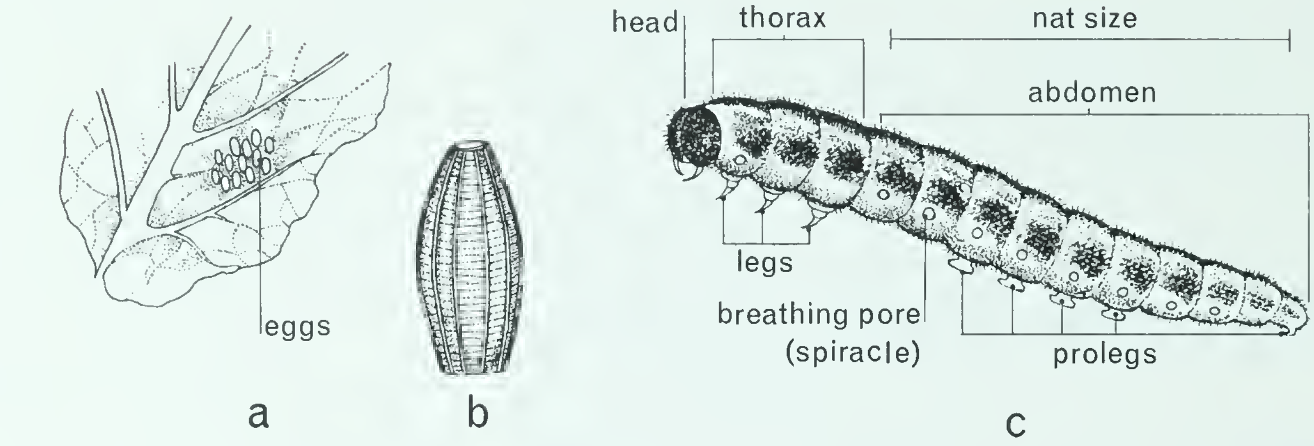
One of the commonest insects in a garden in summer is often called the 'cabbage white butterfly' although its correct name is the large white butterfly (*Pieris brassicae*). You can usually see these insects flying over a vegetable patch and sometimes settling on plants. By watching them we can learn quite a lot about their habits, and their likes and dislikes.

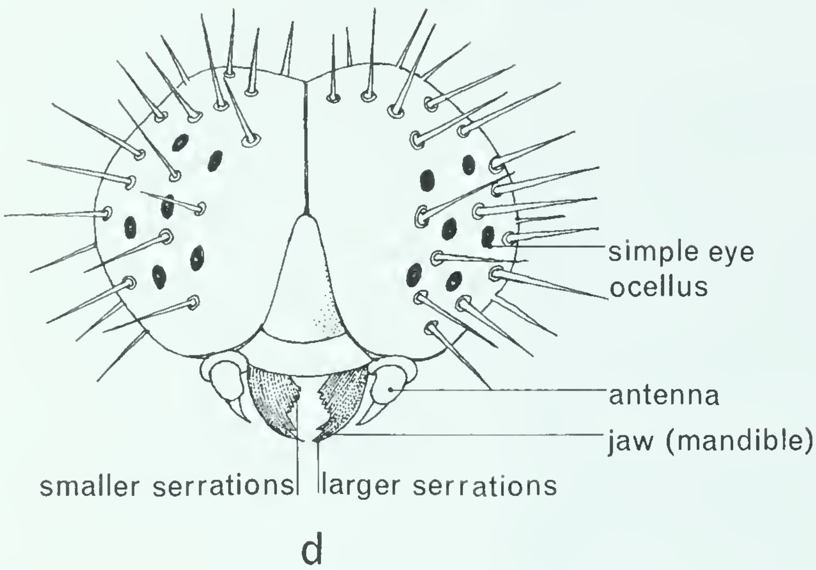
As you walk about outside keep your eyes open and if you see a large white, or several of them, watch for a while. They are not just flying around in an aimless manner, and sooner or later, if you look carefully you may be able to tell what they are doing.

Here are some things you might try to find out:

1. As they fly around, can you see two butterflies coming together. They seem to touch each other and then separate. They may do this several times and even settle on a plant together. They are probably pairing and soon afterwards the female may start to lay a batch of eggs.
2. Watch as they separate again and see if one of them alights on a plant and stays there. Notice what kind of plant it is.
3. If you go too near you may disturb the butterfly. But after it has flown off go and look carefully where it has settled. Can you find any eggs ? Look under and on top of other leaves of the same kind of plant. You should look for a patch of eggs about the size of a sixpence, which will be bright yellow.
4. The plant on which you have noticed the large white may well be a cabbage or one of the same family – the Cruciferae. Look on a good many cabbage leaves and see if you can find caterpillars; you will probably find them on those cabbages where the leaves have been eaten into holes.

The drawings in figures 119 and 120 show the stages in the life history of the large white butterfly and the difference in the arrangement of the black markings on the wings of the male and female.





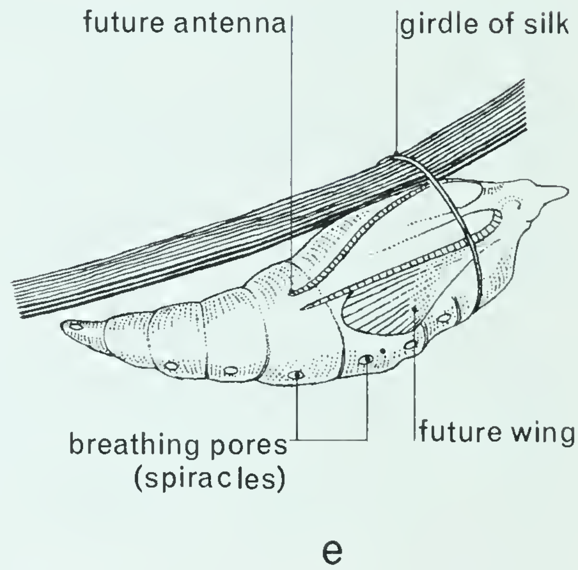


Figure 119
The life history of the large white butterfly (*Pieris brassicae*).

a. Eggs laid singly on a cabbage leaf.

b. A single egg × 20. Note the ridges on the sides.

c. A fully grown larva.

d. The head of a larva × 8.

e. Pupa attached to a twig.

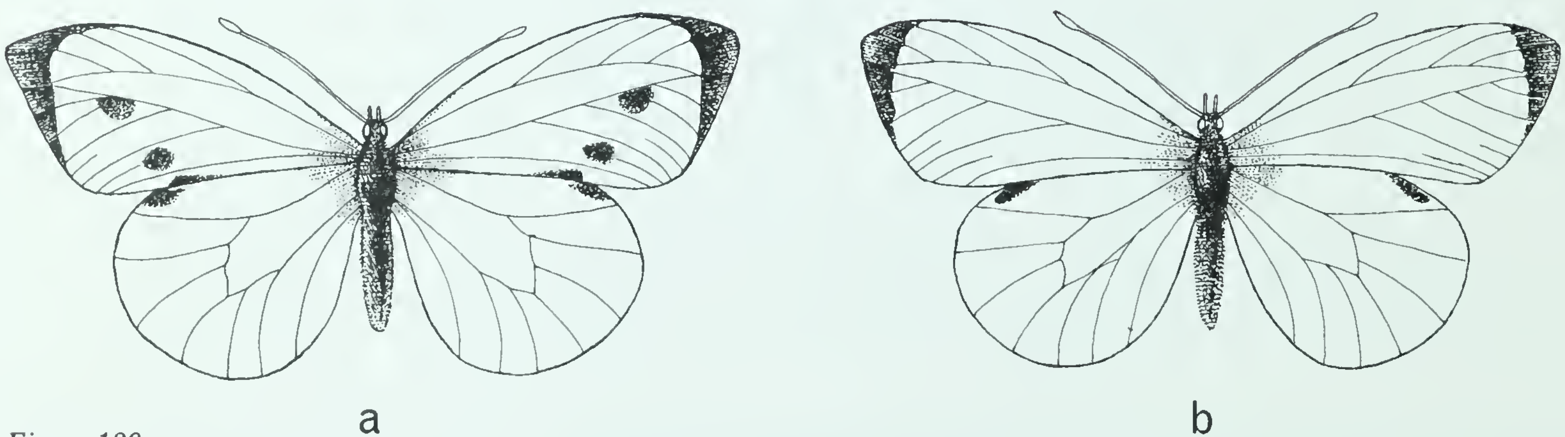


Figure 120
The large white butterfly (*Pieris brassicae*).

a. Adult female

b. Adult male

9.11 Investigating the life history of the large white butterfly

The caterpillars of the large white are often all too common in a cabbage patch and you may be able to find the eggs as well. You can keep the eggs, hatch them, and observe them develop into caterpillars. You can also compare the life history of this insect with that of the locust.

This is what you should do:

1. Examine an egg with a hand lens and draw it. What colour is it? Compare the egg you have drawn with those in figure 119*a*.
2. Prepare a small plastic box about $5 \times 3 \times \frac{3}{4}$ inches by lining it with a sheet of absorbent paper (blotting paper or even newspaper will do) cut just larger than the bottom of the box. With scissors make a small cut from each corner towards the centre. Press the paper into the box and it will then fit the bottom and up the sides.
3. Put the piece of cabbage leaf on which eggs have been laid into the box and add another *small* piece of fresh cabbage leaf, putting the lid on firmly.
4. The eggs will hatch more quickly if they are kept warm at about 24°C but they should not be put over the pipes or in the sun.
5. Every day examine the eggs through the transparent lid to see how they are getting on. Are they still yellow? If they are becoming darker it means that they will soon hatch, since the black colour is due to the head of the caterpillar inside the egg shell.
6. Note the date on which the caterpillars hatch from the eggs and record it as in table 1. What do the caterpillars do as soon as they hatch? It may be possible for you to measure a caterpillar (in mm) although it will be very small. If you succeed, record its length in your table of growth.

		Notes on changes in appearance of caterpillars
Date eggs hatch	?	
Length (in mm) of caterpillars at hatching	?	
at 1 week old	?	
at 2 weeks old	?	
at 3 weeks old	?	

Table 1
Record of growth of caterpillars of the large white butterfly.

7. The caterpillars will need to be fed and to do this you should first remove the paper from the box with the cabbage leaf and caterpillars on it, then re-line the box with a fresh piece of paper. Next, without touching the caterpillars with your fingers either brush them with a paint brush back into the box or, if they are on the old cabbage leaf, put this back in the box with a piece of fresh cabbage leaf on top. Replace the lid. They can stay in the small box until they are about 10 mm long, and then they must be transferred to a larger plastic box about $7 \times 4\frac{1}{2} \times 2\frac{1}{2}$ inches. You should change the paper and give them fresh food every day, otherwise they may get diseased. If you want to try the experiment described in section 9.13 you must start it now.

8. Each week measure one of the caterpillars and when they are about 30 mm long you should draw one, labelling the parts of the body. Have they got special jaws for feeding? Has their colour changed at all while they have been growing? Using a hand lens focus on the head of one of the caterpillars and watch the way it feeds. How does it use its legs and prolegs? (See figure 119.)

9. You will remember that in the locust the skin was hard and the nymphs, as they grew, had to moult. In the large white the skin of the caterpillar is soft and can stretch as the caterpillar gets larger. But can it go on stretching throughout the life of the caterpillar or have you noticed that the caterpillar casts its skin every now and then? Does it eat the cast skin?

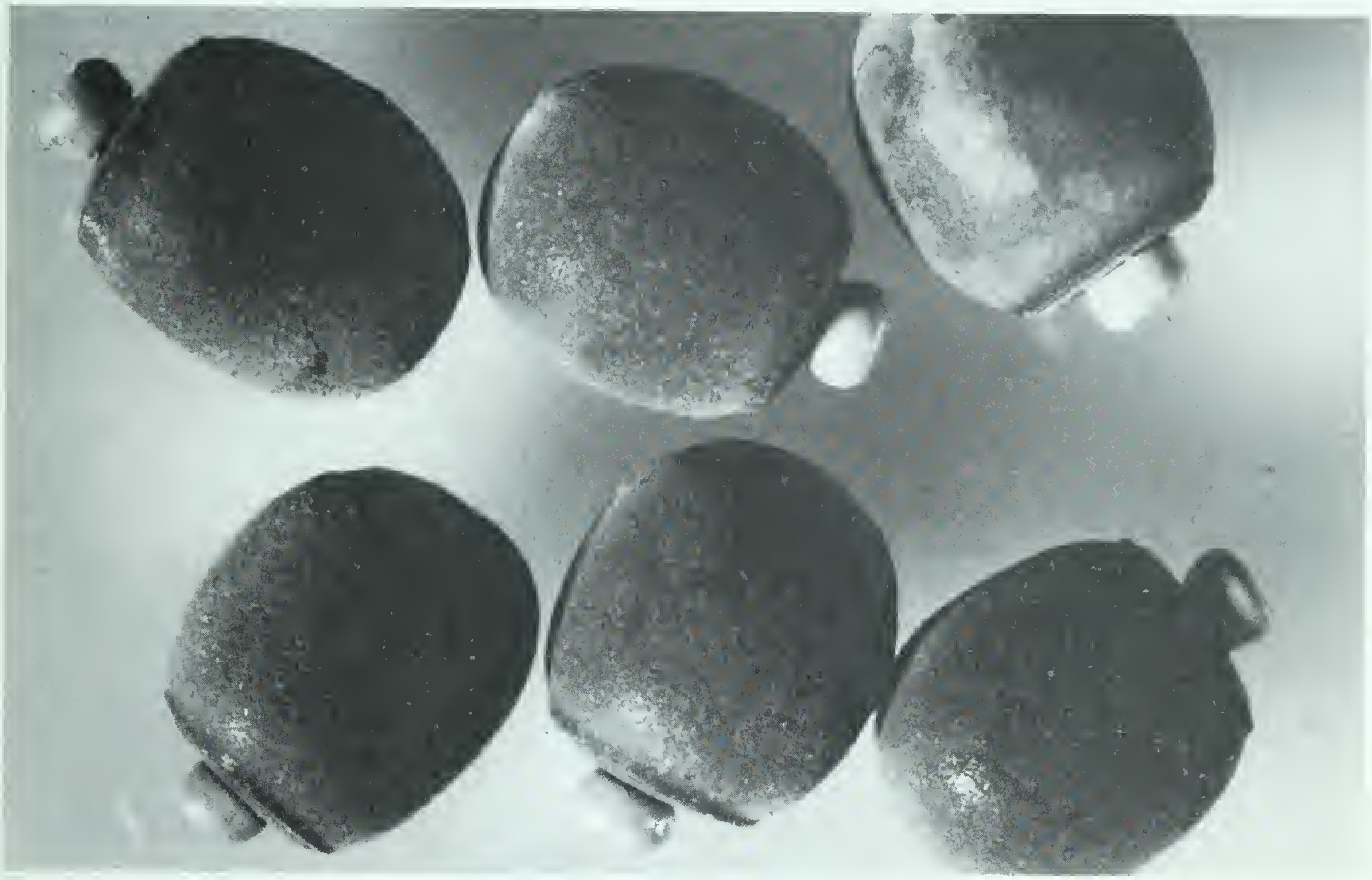
Figure 121
Some insect eggs.

a. Egg cocoons of the cockroach (*Periplanata americana*) × 10. Each cocoon contains a number of eggs. *Photo, Dr Otto Croy.*

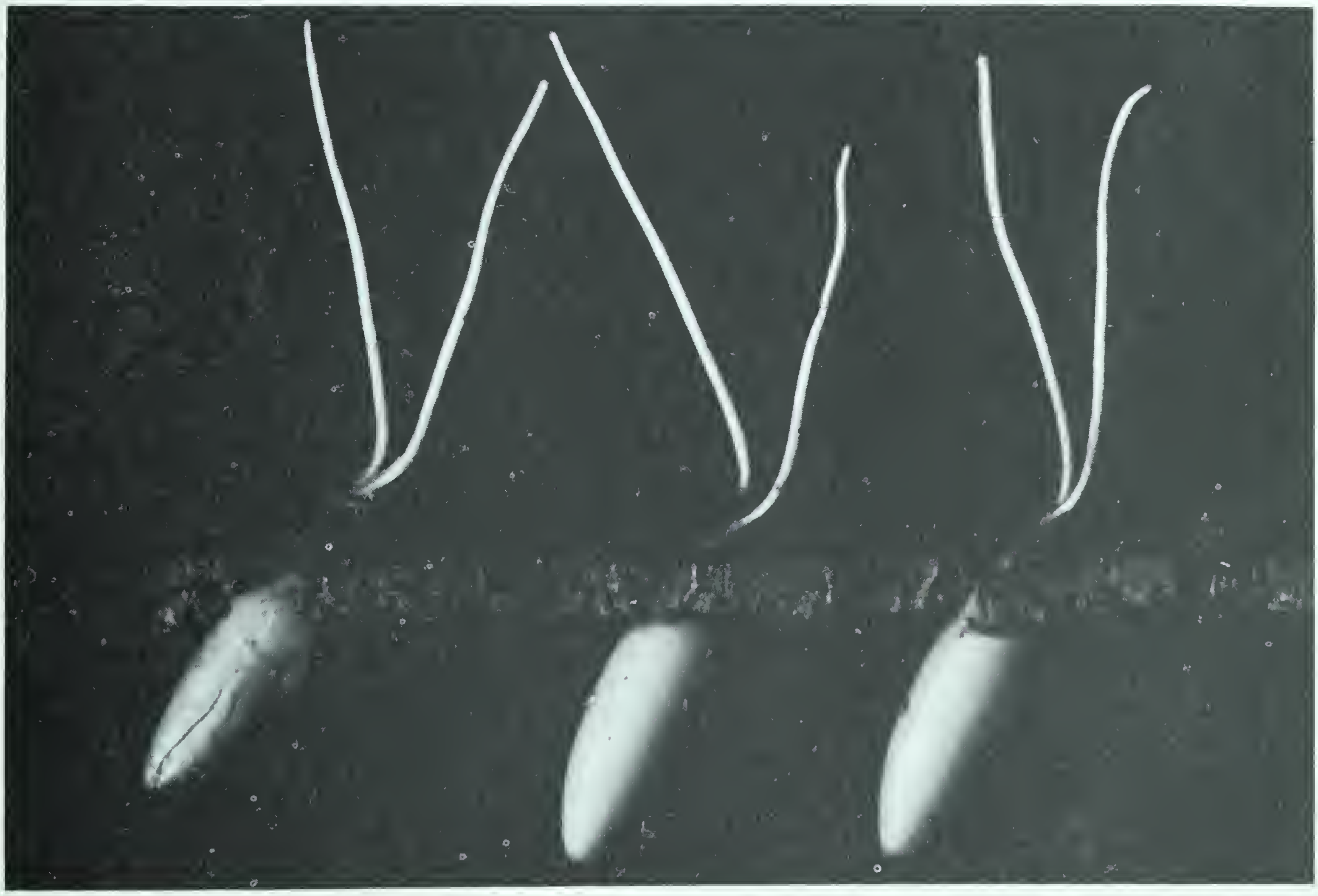
b. Eggs of the stick insect (*Carausius morosus*) × 5. Note the cap to each egg. *Photo, Dr Otto Croy.*

c. Eggs of the water stick insect (*Ranatra linearis*) × 15 showing the long breathing tubes. The eggs are laid in the stems or leaves of water plants. *Photo, Professor Hinton.*

a



b



c

10. When the caterpillars are about 40 mm long you should look at them several times during the day. The first sign that something is going to happen is that they will stop feeding and seem to get shorter, plumper, and darker in colour. Each caterpillar moves its head from side to side and spins a mat of silk on the leaf and a long thread round the middle of its body attaching it to the silk pad. Watch to see what happens next.

9.12 A strange event in the life of the large white butterfly

The caterpillar (or *larva*) does not suddenly turn into a butterfly but something else occurs first. The skin hardens and at the same time the body becomes shorter. The skin then starts to split from the head end and is shed revealing a chrysalis (or *pupa*) which does not look at all like the larva. The skin of the pupa gradually hardens and you may be able to see the outlines of the future legs, wings, and antennae of the butterfly.

Draw one of the pupae and label, on your drawing, the parts of the future butterfly which you can make out.

This rapid change is called metamorphosis. We found a similar event in the tadpoles of *Xenopus* and our native frogs and toads (Chapter 6). In the same way the change from the nymph to the adult stage in the locust was a metamorphosis. Can you think of any other examples?

After the caterpillars have formed pupae (pupated) the pupae should be placed on a thin layer of damp peat in a plastic box and kept at about 24°C. Every day you should sprinkle the pupae with rain water through a fine spray. Why should this be done?

9.13 Experimenting with the larvae of the large white butterfly

If you have ever found the pupae of the large white you may have noticed that they are not always the same colour. The large white is able to complete its life history twice during the summer, and sometimes even three times.

In summer the caterpillars pupate on the cabbage leaves and the pupae are bright green with indistinct black dots, but this is not so with the caterpillars which are fully grown by the autumn. This last brood is usually ready to pupate before the first frosts and when there is not so much sunlight. They leave the cabbage leaves after moulting for the last time and crawl to a fence or wall on which they pupate. These winter pupae are usually greyish-white with distinct black dots.

In order to find out whether the caterpillars are affected by the lightness or darkness of the food on which they feed you could try to produce these different coloured pupae by keeping one set of caterpillars (the control set) on a normal light background and one set on a dark background and see what happens.

1. Using 2 plastic boxes measuring about $7 \times 4\frac{1}{2} \times 2\frac{1}{2}$ inches, line Box 1 with white paper as you did before and Box 2 with black paper.
2. Put the same number of caterpillars, grown to about 10 mm long, in each box and a piece of cabbage leaf.
3. Put a small piece of damp cottonwool in the corner of the boxes.
4. Line the lid of Box 2 with black Cellophane or black tissue paper.
5. Replace the lids on both boxes and keep them in a temperature of about 24°C. Make a note of what you have done, leaving a space to record your results like the imaginary table below. Remember that the paper and cabbage leaf should be changed in each box every day just as you did for the other caterpillars.

Box	Contents	Colour of Pupae
1	White paper, Cabbage leaf, and 5 caterpillars	5 green with indistinct black spots
2	Black paper, Cabbage leaf, and 5 caterpillars	4 greyish-white with distinct black dots 1 greenish-grey with indistinct black dots

Table 2.

In this experiment the caterpillars in both boxes are fed on green cabbage leaf but in Box 1 they are on a light background and live in the light, while in Box 2 they are on a dark background and live in dim light. The caterpillars in Box 1 are kept under conditions of light which are like those of summer, while those in Box 2 are in illumination more like that of autumn.

If the caterpillars in Box 1 turn into green pupae which match the cabbage leaf, this colour might, under summer conditions out of doors, help to protect them from predators such as birds. On the other hand, if any of the caterpillars in Box 2 turn into greyish-white pupae, this colour could help to protect them in their winter quarters – usually a fence or wall.

Can you think of any experiments you could do in order to find out whether the colour of the pupae of the large white butterfly protects them against birds which are their natural enemies?

9.14 The butterfly emerges

After about two or three weeks, the hard skin of the pupa splits and a butterfly with rather crumpled, damp wings emerges. The wings soon straighten out and dry and the butterfly moves them up and down once or twice before taking off on its first flight.

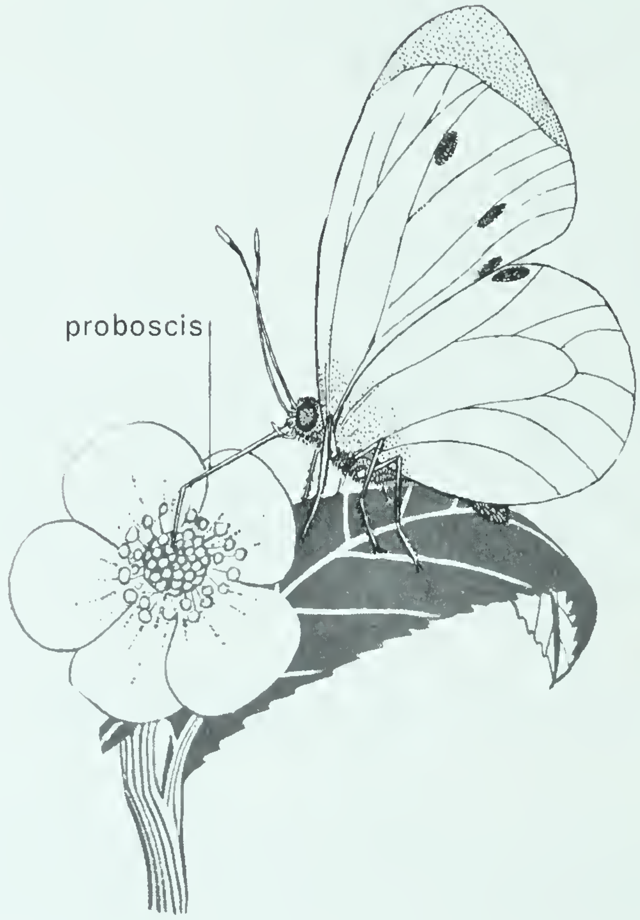


Figure 122
The large white butterfly (*Pieris brassicae*).
The proboscis is extended to reach the honeydew in the nectaries of the flower.

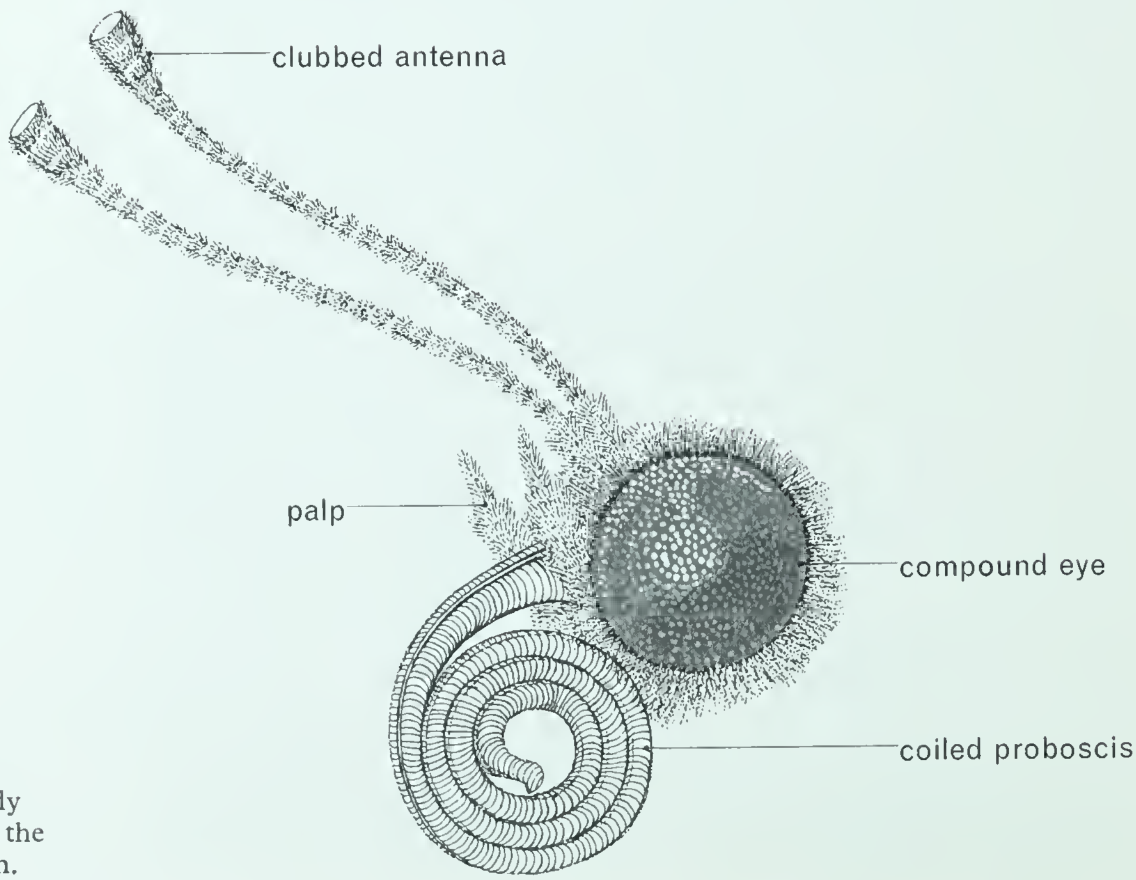


Figure 123
Head of the large white butterfly (*Pieris brassicae*) × 15 showing the proboscis in the resting position.

You may be able to watch the butterflies emerging from some of your own pupae.

How does the butterfly come out of the pupa? What happens to the skin of the pupa?

Look at the butterfly and see that its body consists of the same parts as that of the locust – head, thorax, and abdomen, with three pairs of jointed legs and two pairs of wings.

If you have ever watched butterflies feeding you will see that they do not eat by chewing plants with jaws like the locust or their own caterpillars, but they suck nectar and honeydew by means of a long tongue called a *proboscis*. This is usually kept coiled up like a spring beneath the head but can be uncoiled to probe into a flower for nectar or to drink from drops of dew. (See figures 122 and 123.)

9.15 The pairing of butterflies

If we want to mate butterflies in the laboratory we must provide them with plenty of space. The type of cage used is called a pairing cage and this can easily be made out of any large box with one side covered with fine netting.

About a dozen pupae should be put in the pairing cage. Put the cage in a window where it will be in the sun. When the butterflies emerge you can watch them and see how they behave to each other. You should provide twigs as perches in the cage and also cotton-wool soaked in sugar solution for the butterflies to feed on.

Watch the butterflies after they have emerged from the pupae and see if you can find out more about them and answer these questions:

a. How can you tell the difference between the males and the females?

b. Do the males display to the females and, if so, how do they do this?

c. How do they mate?

d. Do they mate while they are clinging to the twigs or while they are flying around?

9.16 Comparing the life history of the locust and the large white butterfly

In watching locusts (Chapter 8) and the large white we have found out that the locust passes through three stages in its life history – egg, nymph, and adult, while the large white butterfly passes through four stages – egg, larva, pupa, and adult. The locust nymph, when it hatches from the egg, is very like the adult insect except in the matter of size and its lack of wings.

Its way of feeding is also like the adult. Nymphs feed nearly all the time and grow continually. At each moult the nymph comes out a size larger and we say that such a type of life history is an *incomplete metamorphosis* in which there is no 'change-over' stage (as there is in the butterfly – the pupa).

The life history of the large white butterfly contrasts greatly with that of the locust, for the larva that hatches from the egg is quite different from the adult. The larva changes into a pupa and finally into the adult butterfly. This is an example of an insect which undergoes a *complete metamorphosis* in which the pupa is the 'change-over' stage. As we said, the large white in most years is able to complete its life history twice and occasionally even three times during the summer. The last batch of pupae remain as pupae throughout the winter, the butterflies emerging the following summer.

9.2 Plant lice (aphids) have a curious way of reproducing

Most insects, like the locust and the large white butterfly, lay their eggs in places where the young, when they hatch, can immediately start to feed. But in some the eggs are not laid at all but are kept inside the body of the female insect where they hatch and start developing. Eventually the young are born alive. Animals which produce their young alive are called *viviparous*. Plant lice are examples.

Plant lice (or aphids as they are more correctly called) are well known enemies of the gardener and it is a familiar sight in late spring and summer to see the young shoots of plants with curled and shrivelled leaves. If you look underneath one of these leaves you will most probably find a large number of aphids, some larger than others. There are many different kinds of aphid which attack many different kinds of plants. One of the best known is the bean aphis (*Aphis fabae*) which is black and is to be found clustered on the tender top shoots of broad beans. You may also find aphids on the young shoots and leaves of roses, chrysanthemums, and lettuce.

You are provided with aphids on a leaf.

1. Focus one of the large aphids under a hand lens or, better still, a dissecting microscope.
2. With the aid of figure 124*a* identify the different parts of the body of the aphid. Note the long antennae, the fat abdomen, and the two *cornicles* which produce a waxy or sticky substance.
3. Now look at the other aphids on the leaf. Are there any with wings ? Are they all the same size or are there some very small ones ?
4. Turn the leaf, if you can, so that you are looking at the aphid sideways on. Can you see the long *proboscis* under the head ?
5. Look more closely at the abdomen of one of the large aphids. You will need to use a dissecting microscope for this, and focus up and down by turning the focusing knob first one way and then the other very slightly. Can you make out any young aphids, as yet unborn, inside the abdomen of a female (see figure 124*b*).

The large wingless aphids are all females and are called 'stem mothers' because inside each of them are a number of young ones

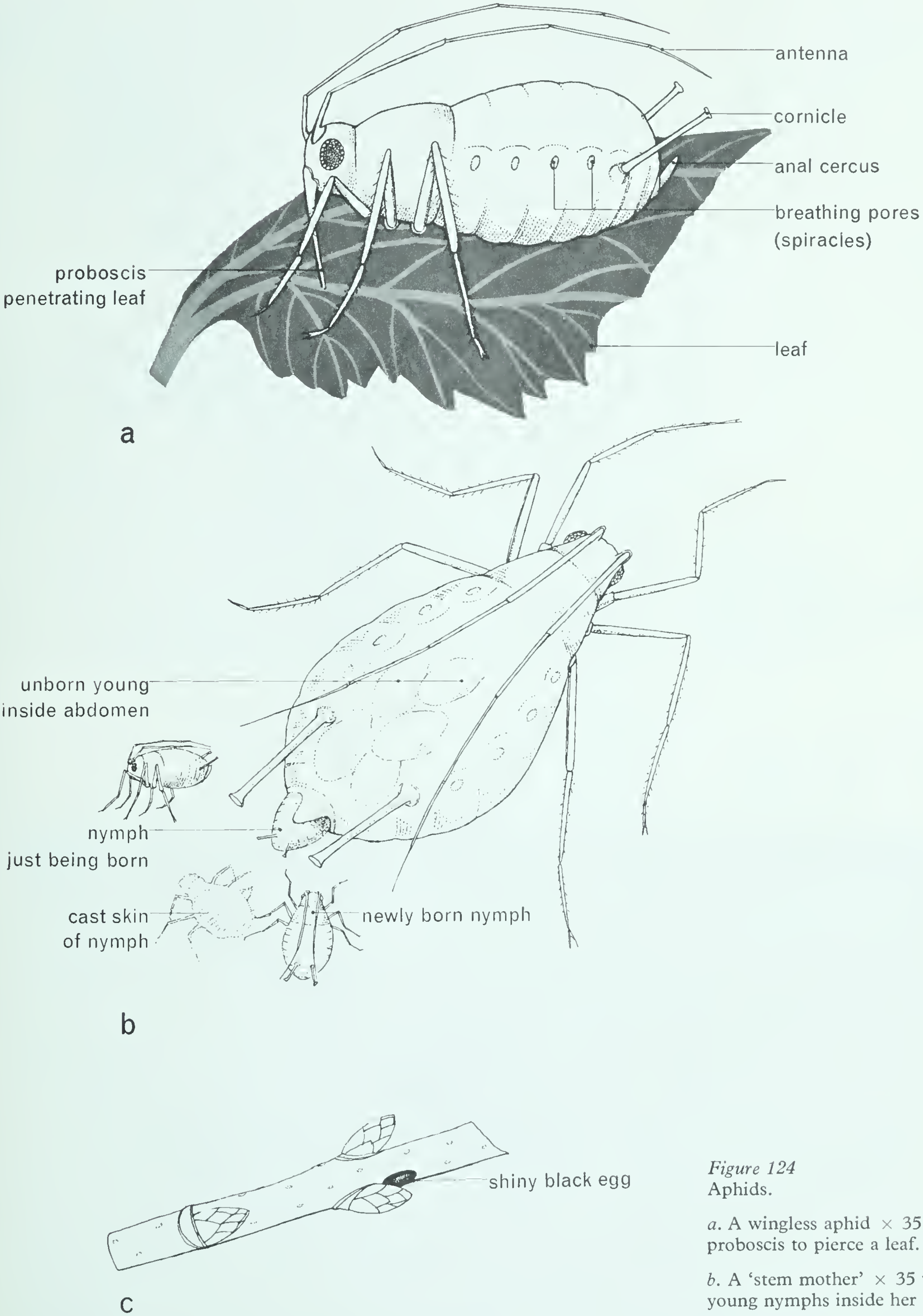


Figure 124
Aphids.

a. A wingless aphid × 35 using its proboscis to pierce a leaf.

b. A 'stem mother' × 35 with young nymphs inside her abdomen.

c. Winter egg of an aphid on a twig × 2.

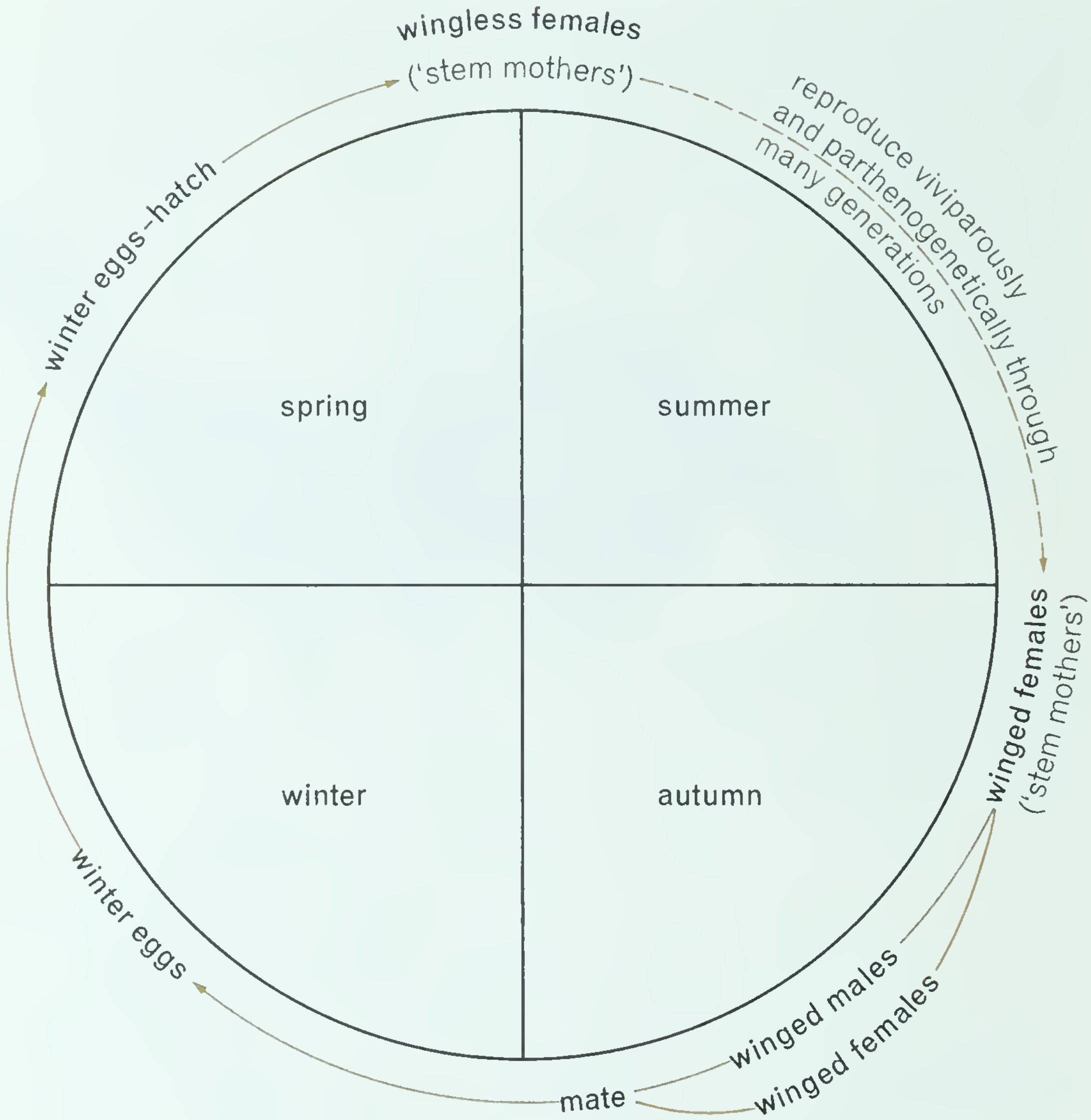


Figure 125
The reproductive cycle of aphids during one year.

Figure 126
A winged aphid × 9.
Winged males and females appear in the autumn. *Photo, S. Beaufoy.*

Figure 127
Ants collecting honeydew from aphids.
Ants stroke aphids with their antennae, causing the aphids to exude honeydew. *Photo*, *S. Beaufoy*.

developing. In the course of twenty-four hours each of these females may give birth to twelve or more young aphids, and you may be able to find one surrounded by offspring of various sizes as in figure 124*b*. These young nymphs feed and grow at a very rapid rate so that in eight to ten days they will be giving birth themselves to a generation of young ones.

During the summer all the aphids you will find, whether winged or wingless, are females and they can go on reproducing generation after generation of young ones without a male to fertilize the eggs inside them. A single female aphid may be responsible for over a thousand young during the summer but the rate of reproduction slows down in cooler weather. This ability of the female to reproduce without a male is called *parthenogenesis* (Greek, *parthenos* = virgin, *genesis* = production) and we shall find other examples among insects of this strange method of reproduction.

In the autumn, however, winged males are born which mate with the winged females (see figure 126). These females fly off to a plant such as a tree or shrub which, unlike the food plant of the aphid, does not die down in winter. They lay a few eggs on the bark, usually in the angle between a bud and the stem (see figure 124*c*). These eggs have very hard shells which protect them from frost. In the spring they hatch into females ('stem mothers') which start once more to reproduce parthenogenetically. Figure 125 shows the cycle of reproduction of aphids during one year.

In order to grow so rapidly aphids are constantly feeding. They do this by digging the proboscis into a leaf and then sucking the sap (see figure 124*a*). That is why, when there are a great many aphids all feeding on a plant, the leaves become shrivelled. One of the first signs that there are aphids on a plant is the sticky honeydew on the leaves. Because they take in so much moisture in the form of sap, the aphids have to get rid of the surplus. This they constantly exude as honeydew from the anus at the end of the abdomen.

Honeydew is very attractive to ants. If you watch a plant which is infested with aphids you can often see a trail of ants walking up the stem and along the leaves. Look more carefully and you may see an ant stroking an aphid with its antennae (see figure 127). Aphids are often called 'ant cows' because of this, and ants may even transport aphids from one plant to another, moving them to fresh feeding grounds and stroking them for honeydew like milking cows.

Fortunately for the gardener, aphids have many enemies including birds and other insects particularly ladybirds which help to keep their numbers down.

9.3 Insects and their enemies

Like all other animals insects have their enemies, and in order to survive they must protect themselves in some way or another, especially against such animals as birds, spiders, frogs, toads, insect-eating mammals, and even other insects. All these predators are intent upon getting an insect meal either for themselves or their offspring, and the insects must try either to escape detection or to defend themselves. Some, such as ants, fight with their mandibles, others sting, such as bees and wasps. Many which can do neither of these things make themselves look fierce either by possessing formidable but often useless weapons, like the huge jaws of the stag beetle (see figure 128) or by adopting threatening attitudes like the praying mantis (see figure 129). Many insects are distasteful to birds and other animals and to show this they are often coloured brightly like the yellow and black spotted caterpillar of the large white butterfly. Other insects rely on speed to escape from danger by running, jumping, or flying away.

In some insects their colour exactly matches their background and so long as they remain still, they are safe. If you did any experiments with the pupae of the large white butterfly you may have found that the green pupae which matched the colour of the cabbage leaf, were not eaten, but when tied to a brown fence they were quickly found by birds.

9.31 Insects that protect themselves by camouflage

Some insects escape detection by resembling something else, in other words by camouflaging themselves. The stick insect (*Carausius morosus*) (see figure 130) is an excellent example and can be kept

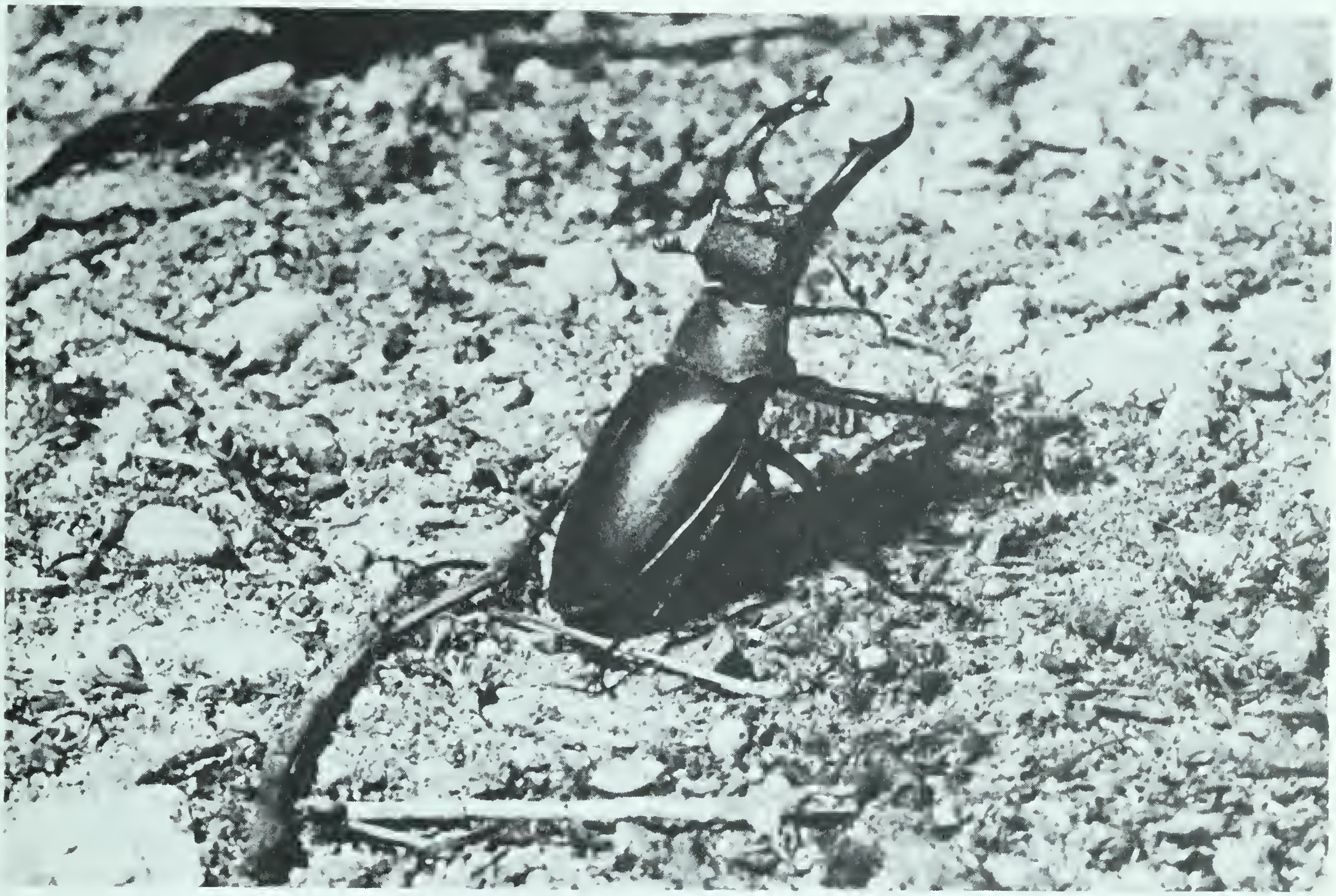


Figure 128
A male stag beetle (*Lucanus cervus*) × 1.
The huge jaws are useless because they cannot move. In the female the jaws are smaller and can be used for attack. *Photo by R. H. Noailles.*

quite easily in the laboratory since all it requires is a supply of fresh privet on which to feed. It can be kept in any kind of cage such as an old aquarium or accumulator jar with a well-fitting lid of perforated zinc. The food plant should stand in a jar of water inside the cage.

Stick insects are usually most active during the night, but can sometimes be seen feeding during the day as well. They are found in tropical countries and because they move slowly and cannot defend themselves by biting or stinging, they make a particularly good meal for birds and lizards which are their natural enemies.

Take a stick insect out of a cage and have a closer look at it. Find the various parts of its body.
Here are some questions for you to answer:
1. In what way is the stick insect *not* a typical insect?
2. The legs of the stick insect are far apart which makes it walk with a swaying motion. Can you see why the legs are so far apart?
3. Using a hand lens, examine the legs of the insect. Are they in any way like the legs of the locust, especially the feet?

While you are keeping stick insects there are other things you could find out about them – their life history and habits for instance. Males are extremely rare but, like aphids, the female stick insects can produce fertile eggs without being fertilized. Thus they provide another example of reproduction by parthenogenesis.

Figure 129
A praying mantis (*Mantis religiosa*) × 2.
The mantis is adopting a threatening attitude with its front legs drawn up. *Photo by R. H. Noailles.*

Here are some more questions which you could try to answer after you have watched the stick insects for a while:

1. What does the egg of the stick insect look like? Focus an egg under a hand lens and draw it. Is it in any way like the egg of the locust?

2. Are the eggs laid in any special way – in a cocoon, attached to the leaves, or in an egg pod like the locust?

3. What hatches from the egg – a larva or a nymph, and how does hatching take place?

4. Does the stick insect undergo a complete or an incomplete metamorphosis?

5. How do the stick insects climb up the sides of the glass cage? (You will need to use a hand lens to answer this.)

Figure 121 shows the eggs of various insects and the hard cocoon of a cockroach.

9.32 Finding out about the ways in which insects protect themselves

We have discussed some of the ways in which insects defend and protect themselves (section 9.3). But there are many others, and we must not forget that some insects may have more than one means

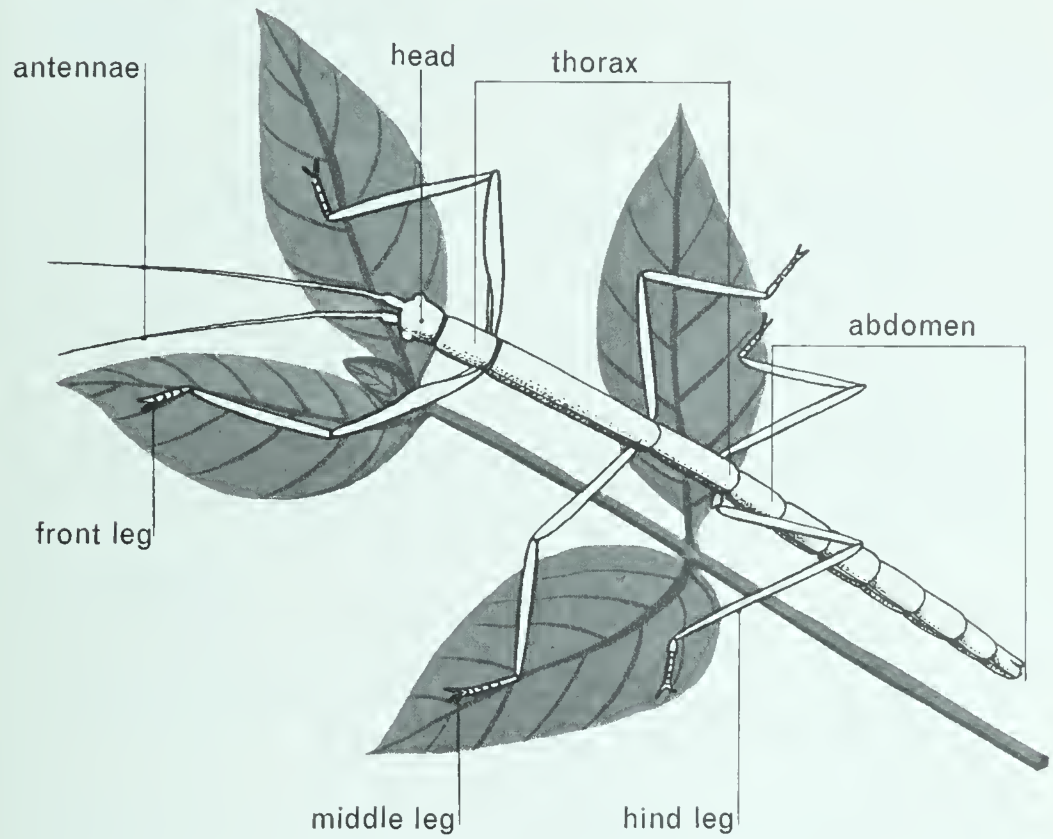


Figure 130
An adult stick insect (*Carausius morosus*) × 1.
The stick insect belongs to the same order of insects as the praying mantis – the *Phasmidae* – but has no wings.

of protection. Also, at one stage of their life history they may be more defenceless than at another. The caterpillars of some butterflies, for instance, are soft and juicy, making an excellent meal for birds which would shun a brightly coloured butterfly.

When you are next outside you could try to discover for yourself how the insects you find are protected from their enemies.

Table 3 lists some of the ways in which insects protect themselves. Can you think of any others? If you can, add them to the table. You could also put in any other insects you have watched. Now try to complete the table in the same way in which it has been done for the wasp.

Insect	By moving fast	By attitude	Resembling something else	Resembling background		Offensive colour	Offensive weapon
				By shape	By colour		
Wasp	Flight	—	—	—	—	Yellow and black striped body	Sting
Large white butterfly							
Locust							
Stag beetle							
Ladybird							
Leaf miner							
? ?							

Table 3
Methods of protection.

9.4 The advantages of being an insect

In Chapter 1 we pointed out that there were nearly three quarters of a million insects in the world. They are to be found in abundance everywhere except in the sea, although there are a few species which can even live there too. They are found in the polar regions, in steamy equatorial rain forests, in dry deserts, and on high mountains.

Without a doubt one of the greatest advantages insects possess is their hard, yet light, outside skeleton which protects them against their enemies and can be adapted for a variety of different uses such as mouthparts and other body structures. This *exoskeleton* as it is called, keeps the insect dry and, more important still, prevents it from losing moisture from its body. Thus insects can live in very hot places without fear of drying up, and in very cold places without becoming frozen.

Probably one of the largest insects is a kind of tropical stick insect which reaches a foot in length; while one of the smallest is a beetle no more than 0·2 mm long which lives among fungi. But the fact that insects never grow very large is in itself an advantage, because the quantity of food they require is so small they can survive in places where many other animals would starve. For instance, one or more leaf-mining insects can even live and feed between the upper and lower surfaces of a leaf and there is a kind of weevil which can complete its life inside a single small seed.

Summary

We have followed the life of the large white butterfly, and have learnt that whereas the locust passes through only three stages in its life history a butterfly passes through four. Each involves a rapid change or metamorphosis, from one stage to the next. Female stick insects produce young without a male (parthenogenetically) and the young nymphs which hatch from the eggs develop gradually like those of the locust (incomplete metamorphosis). Female aphids, on the other hand, give birth to their young alive and can also produce young without a male. They are therefore viviparous and parthenogenetic.

In order to survive all insects must have some way of protecting themselves. Many have more than one way of doing this.

Although we have been concerned in this chapter with insect lives and with methods of protection, there are many other interesting things to be found out about insects. Since they occur everywhere there are plenty of opportunities of doing so. How do insects move about on land, in the air, and in water? How much are they aware of their surroundings? How well can they see? Can they see colours and can they hear? How do they communicate one with another? These are only a few of the interesting things about insects which you could investigate for yourself.

Background reading

A strange life cycle – the large blue butterfly

Among the butterflies of Britain the large blue (*Maculinea arion*) occupies an odd position, being one of the most beautiful but one of the least well known. The photograph (figure 131) gives a good idea of its size and markings, but to see its real beauty we need a colour photograph, or better still, the insect itself. Few of us are likely to find the butterfly alive because its homes are now confined to an area of the Cotswolds and a few isolated places in Devon and Cornwall. However, towards the end of last century it occurred in a number of other areas where it is now extinct and, from these, quite large collections were made, many of which can be seen in our museums today. They are well worth a visit. Oddly enough, although the insect is so rare, the sort of places where it lives vary greatly from glades in woods, to open grassland, and even sea cliffs. However, in all its haunts there occur the wild thyme (*Thymus drucei*) and nests of two common red ants – *Myrmica scabrinoides* and *M. laevonoides*.

The butterflies appear in June and fly only when the sun is shining. One of the reasons why it is difficult to observe them is that during sunny weather they tend to be on the wing only for about three hours, early in the morning. For the rest of the day they sit about on the vegetation giving no more than an occasional flutter. To rouse them, the plants must be beaten with a stick. The eggs are laid on the wild thyme, chiefly on the unopened flower buds. Usually, only one egg is laid on each bud and considering the size of the butterfly, these are small, measuring only about 0·5 mm across and 0·3 mm high. They hatch in approximately eight days but the period can vary by as much as three days, depending on the weather. The young larva is a small greenish yellow grub about 0·8 mm long with an uncanny resemblance to the flower bud on which the egg was laid. It feeds on the flowers of the thyme which provide its only food during the period, lasting about twenty days, of its first three moults. By now the caterpillar is just over 3 mm long. After the third moult, which lasts four days, the large blue larva rests for several hours and then starts wandering about aimlessly. It is fat, grub-like, and clumsy in its movements, and shows no further interest in eating thyme flowers. It seems to be waiting for something. But what?

If a passing red ant happens to come near the larva it immediately takes a great interest in it, caressing it excitedly with its legs and waving its antennae. Then there follows an extraordinary courtship which may last for an hour or more during which the ant can be seen to suck up little beads of liquid which flow from a honey gland on the back of the caterpillar situated on the tenth segment. The production of honey is stimulated by the activities of the ant which leaves the larva now and then to walk round and round, but each time returns to carry on the 'milking' operation. Meanwhile, other ants may have arrived to share the prize but, apparently, it is a question of first come first served, and they soon disperse leaving the original captor in possession.

After an hour or more the appearance of the larva begins to change, the segments of the thorax swelling up while the rest of the body remains its normal shape (figure 132). This seems to be the signal for the next stage in the story, for the ant now seizes the caterpillar in its jaws and carries it off triumphantly to the entrance of its nest, disappearing with its captive below ground. Once in the ants' nest the larva remains there for the rest of its life and another strange thing happens. It ceases to be herbivorous and becomes a carnivore feeding on the young larvae of the ants which it devours eagerly. It now grows rapidly and as winter approaches it settles down to hibernate among the ant larvae tended by the ants themselves. With the arrival of spring it starts feeding once more and growth is finally completed in early May. Its appearance is now pinkish white and very shiny, its skin giving the impression of being stretched to bursting point. This is probably not far from the truth for during the time of its captivity among the ants its length has increased fivefold from 3 mm to nearly 15 mm without a further moult!

At this stage the larva changes into a pupa – a whitish object which hangs by a silk pad for a few days from the roof of the nest and then drops to the floor. Here it remains until the perfect

Figure 131
The large blue butterfly (*Maculinea arion*) life size. *Photo, S. Beaufoy.*

butterfly emerges about three weeks later. It crawls along the tunnels of the ants' nest, its wings still folded, and eventually arrives above ground and climbs up a grass stem or onto some other suitable vegetation where its wings can hang down and dry. Within an hour it is ready for its first flight.

So ends the strange story of the life cycle of the large blue butterfly. We may well ask how the partnership of butterfly and ant came about in the first place. The answer must remain no more than a guess. But it is perhaps worth adding that within the family *Lycaenidae* (the 'blue' butterflies) there are a number of other species which will not thrive even in captivity, unless ants are present. How important the ants really are for these species we do not know, but it is unlikely that any other life cycle depends on them quite so completely as that of the large blue.

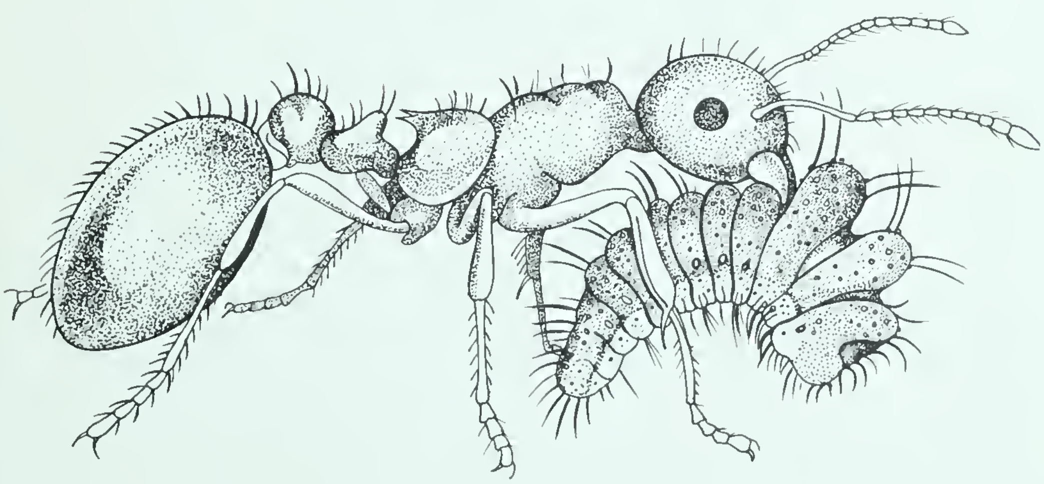


Figure 132
An ant carrying a caterpillar of the large blue butterfly × 11. *From Frohawk, F. W. (1920)* The natural history of British butterflies, *published by Hutchinson.*

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Other Nuffield Biology publications

Teachers' guide I		*Introducing living things*
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Teachers' guide III	Text III	*The maintenance of life*
Teachers' guide IV	Text IV	*Living things in action*
Teachers' guide V	Text V	*The perpetuation of life*

Keys to small organisms in soil, litter, and water troughs

Film Loop notes