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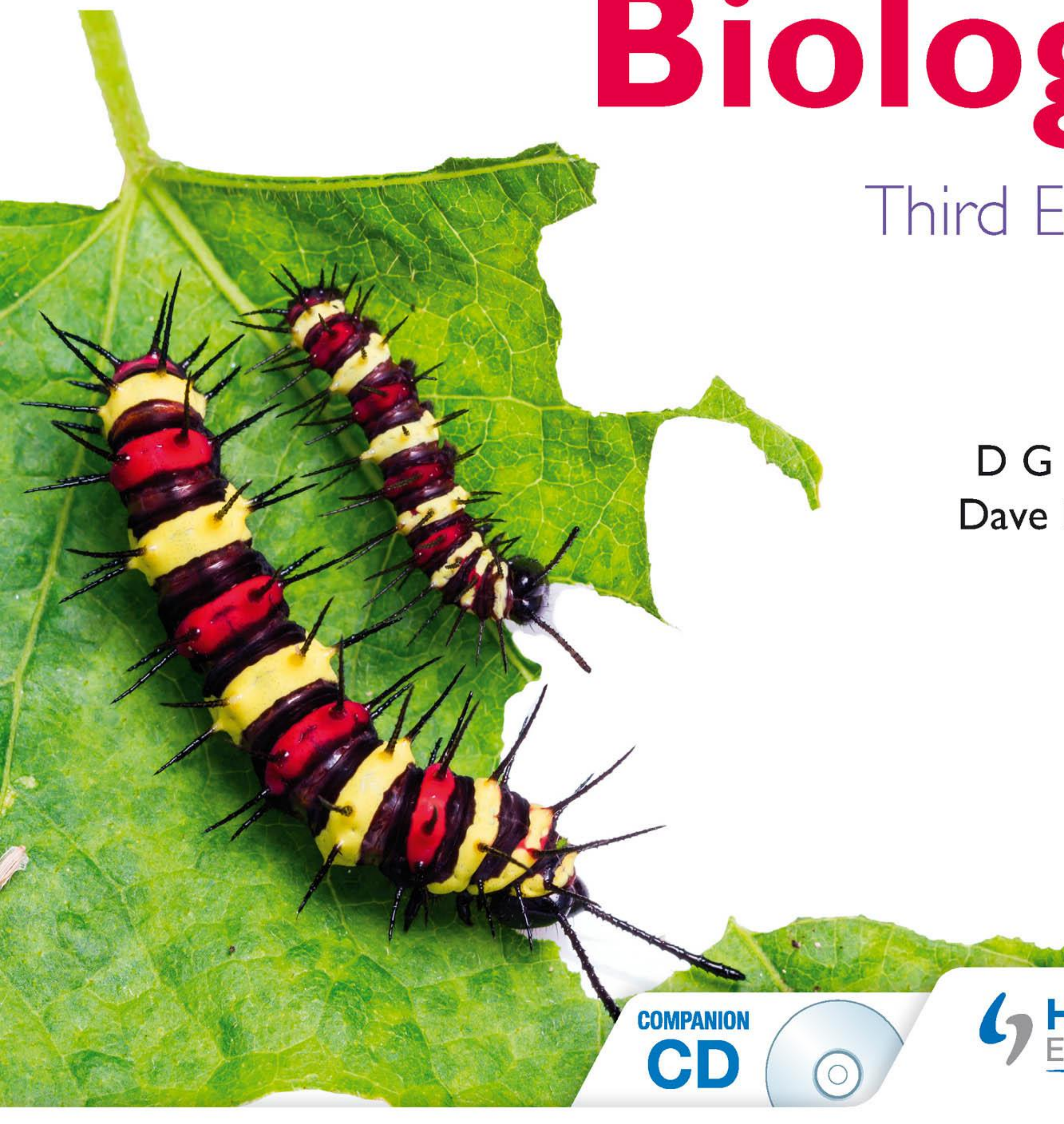

D G Mackean
Dave Hayward

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Third Edition

D G Mackean
Dave Hayward

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To the student

Cambridge IGCSE® Biology Third Edition aims to provide an up-to-date and comprehensive coverage of the Core and Extended curriculum in Biology, specified in the current Cambridge International Examinations IGCSE® syllabus.

This third edition has been completely restructured to align the chapters in the book with the syllabus. Each chapter starts with the syllabus statements to be covered in that chapter, and ends with a checklist, summarising the important points covered. The questions included at the end of each chapter are intended to test your understanding of the text you have just read. If you cannot answer the question straightaway, read that section of text again with the question in mind. There are past paper examination questions at the end of the book.

To help draw attention to the more important words, scientific terms are printed in bold the first time they are used. As you read through the book, you will notice three sorts of shaded area in the text.

Material highlighted in green is for the Cambridge IGCSE Extended curriculum.

Areas highlighted in yellow contain material that is not part of the Cambridge IGCSE syllabus. It is extension work and will not be examined.

Questions are highlighted by a box like this.

The accompanying Revision CD-ROM provides invaluable exam preparation and practice. We want to test your knowledge with interactive multiple choice questions that cover both the Core and Extended curriculum. These are organised by chapter.

Together, the textbook and CD-ROM will provide you with the information you need for the Cambridge IGCSE syllabus. I hope you enjoy using them.

I am indebted to Don Mackean for a substantial amount of the content of this textbook. Since 1962, he has been responsible for writing excellent Biology books to support the education of countless students, as well as providing an extremely useful source of information and inspiration for your teachers and their teachers. Don's diagrams, many of which are reproduced in this book, are legendary.

Dave Hayward

1 Characteristics and classification of living organisms

Characteristics of living organisms
Listing and describing the characteristics of living organisms

Concept and use of a classification system
How organisms are classified, using common features
Defining species
Using the binomial system of naming species

Features of organisms
Identifying the main features of cells

The five-kingdom classification scheme

The basic features of plants and animals
The main features of groups in the animal kingdom

The main features of groups in the plant kingdom
The main features of viruses

Dichotomous keys
Use of keys based on easily identifiable features
Construction of dichotomous keys

Characteristics of living organisms

Key definitions

Movement is an action by an organism causing a change of position or place (see Chapter 14).

Respiration describes the chemical reactions in cells that break down nutrient molecules and release energy (see Chapter 12).

Sensitivity is the ability to detect and respond to changes in the environment (see Chapter 14).

Growth is a permanent increase in size (see Chapter 16).

Reproduction is the processes that make more of the same kind of organism (see Chapter 16). Single-celled organisms and bacteria may simply keep dividing into two. Multicellular plants and animals may reproduce sexually or asexually.

Excretion is the removal from organisms of toxic materials and substances in excess of requirements (see Chapter 13).

Nutrition is the taking in of materials for energy, growth and development (see Chapters 6 and 7).

All living organisms, whether they are single-celled or multicellular, plants or animals, show the characteristics included in the definitions above: movement, respiration, sensitivity, growth, reproduction, excretion and nutrition.

One way of remembering this list of the characteristics of living things is by using the mnemonic **MRS GREN**. The letters stand for the first letters of the characteristics.

Mnemonics work by helping to make the material you are learning more meaningful. They give a structure which is easier to recall later. This structure may be a word, or a name (such as MRS GREN) or a phrase. For example, 'Richard of York gave battle in vain' is a popular way of remembering the colours of the rainbow in the correct sequence.

Key definitions

If you are studying the extended syllabus you need to learn more detailed definitions of some of the characteristics of living things.

Movement is an action by an organism or part of an organism causing a change of position or place.
Most single-celled creatures and animals move about as a whole. Fungi and plants may make movements with parts of their bodies (see Chapter 14).

Respiration describes the chemical reactions in cells that break down nutrient molecules and release energy for metabolism.
Most organisms need oxygen for this (see Chapter 12).

Sensitivity is the ability to detect or sense stimuli in the internal or external environment and to make appropriate responses (see Chapter 14).

Growth is a permanent increase in size and dry mass by an increase in cell number or cell size or both (see Chapter 16).
Even bacteria and single-celled creatures show an increase in size. Multicellular organisms increase the numbers of cells in their bodies, become more complicated and change their shape as well as increasing in size (see 'Sexual reproduction in humans' in Chapter 16).

Excretion is the removal from organisms of the waste products of metabolism (chemical reactions in cells including respiration), toxic materials and substances in excess of requirements (see Chapter 13).
Respiration and other chemical changes in the cells produce waste products such as carbon dioxide. Living organisms expel these substances from their bodies in various ways (see Chapter 13).

Nutrition is the taking in of materials for energy, growth and development. Plants require light, carbon dioxide, water and ions. Animals need organic compounds and ions and usually need water (see Chapters 6 and 7).
Organisms can take in the materials they need as solid food, as animals do, or they can digest them first and then absorb them, like fungi do, or they can build them up for themselves, like plants do. Animals, using ready-made organic molecules as their food source, are called heterotrophs and form the consumer levels of food chains. Photosynthetic plants are called autotrophs and are usually the first organisms in food chains (see Chapters 6 and 19).

Concept and use of a classification system

Key definitions

A **species** is a group of organisms that can reproduce to produce fertile offspring.

The **binomial system** is an internationally agreed system in which the scientific name of an organism is made up of two parts showing the genus and the species.

You do not need to be a biologist to realise that there are millions of different organisms living on the Earth, but it takes a biologist to sort them into a meaningful order, i.e. to **classify** them.

There are many possible ways of classifying organisms. You could group all aquatic organisms together or put all black and white creatures into the same group. However, these do not make very meaningful groups; a seaweed and a porpoise are both aquatic organisms, a magpie and a zebra are both black and white; but neither of these pairs has much in common apart from being living organisms and the latter two being animals. These would be **artificial systems** of classification.

A biologist looks for a **natural system** of classification using important features which are shared by as large a group as possible. In some cases it is easy. Birds all have wings, beaks and feathers; there is rarely any doubt about whether a creature is a bird or not. In other cases it is not so easy. As a result, biologists change their ideas from time to time about how living things should be grouped. New groupings are suggested and old ones abandoned.

Species

The smallest natural group of organisms is the **species**. A species can be defined as a group of organisms that can reproduce to produce fertile offspring.

Members of a species also often resemble each other very closely in appearance, unless humans have taken a hand in the breeding programmes. All cats belong to the same species but there are wide variations in the appearance of different breeds (see 'Variation' in Chapter 18). An American Longhair and a Siamese may look very different but they have few problems in breeding together. Robins, blackbirds and sparrows are three different species of bird. Apart from small variations, members of a species are almost identical in their anatomy, physiology and behaviour.

Closely related species are grouped into a **genus** (plural: **genera**). For example, stoats, weasels and polecats are grouped into the genus *Mustela*.

Binomial nomenclature

Species must be named in such a way that the name is recognised all over the world.

'Cuckoo flower' and 'Lady's smock' are two common names for the same wild plant. If you are not aware that these are alternative names this could lead to confusion. If the botanical name, *Cardamine pratensis*, is used, however, there is no chance of error. The Latin form of the name allows it to be used in all the countries of the world irrespective of language barriers.

People living in Britain are familiar with the appearance of a blackbird – a very common garden visitor. The male has jet black plumage, while the female is brown. Its scientific name is *Turdus merula* and the adult is about 24 cm long (see Figure 1.1). However, someone living in North America would describe a blackbird very differently. For example, the male of one species, *Agelaius phoeniceus*, has black plumage with red shoulder patches and yellow flashes, while the female is speckled brown. It is about the size of a sparrow – only about 20 cm long (see Figure 1.2). A British scientist could get very confused talking to an American scientist about a blackbird! Again, the use of the scientific name avoids any confusion.

The **binomial system** of naming species is an internationally agreed system in which the scientific name of an organism is made up of two parts showing the genus and the species. Binomial means 'two names'; the first name gives the genus and the second gives the species. For example, the stoat and weasel are both in the genus *Mustela* but they are different species; the stoat is *Mustela erminea* and the weasel is *Mustela nivalis*.

The name of the genus (the generic name) is always given a capital letter and the name of the species (the specific name) always starts with a small letter.

Frequently, the specific name is descriptive, for example *edulis* means 'edible', *aquatilis* means 'living in water', *bulbosus* means 'having a bulb', *serratus* means 'having a jagged (serrated) edge'.

Figure 1.1 *Turdus merula* ♂

Figure 1.2 *Agelaius phoeniceus* ♂

If you are studying the extended syllabus you need to be able to explain why it is important to classify organisms. By classifying organisms it is possible to identify those most at risk of extinction. Strategies can then be put in place to conserve the threatened species. Apart from the fact that we have no right to wipe out species forever, the chances are that we will deprive ourselves not only of the beauty and diversity of species, but also of potential sources of valuable products such as drugs. Many of our present-day drugs are derived from plants (e.g. quinine and aspirin) and there may be many more sources as yet undiscovered. We are also likely to deprive the world of genetic resources (see 'Conservation' in Chapter 21).

By classifying organisms it is also possible to understand evolutionary relationships. Vertebrates all have the presence of a vertebral column, along with a skull protecting a brain, and a pair of jaws (usually with teeth). By studying the anatomy of different groups of vertebrates it is possible to gain an insight into their evolution.

The skeletons of the front limb of five types of vertebrate are shown in Figure 1.3. Although the limbs have different functions, such as grasping, flying, running and swimming, the arrangement and number of the bones is almost the same in all five. There is a single top bone (the humerus), with a ball and socket joint at one end and a hinge joint at the other. It makes a joint with two other bones (the radius and ulna) which join to a group of small wrist bones. The limb skeleton ends with five groups of bones (the hand and fingers), although some of these groups are missing in the bird.

The argument for evolution says that, if these animals are not related, it seems very odd that such a similar limb skeleton should be used to do such different things as flying, running and swimming. If, on the other hand, all the animals came from the same ancestor, the ancestral skeleton could have changed by small stages in different ways in each group. So we would expect to find that the basic pattern of bones was the same in all these animals. There are many other examples of this kind of evidence among the vertebrate animals.

Classification is traditionally based on studies of **morphology** (the study of the form, or outward appearance, of organisms) and **anatomy** (the study of their internal structure, as revealed by dissection). Aristotle was the first known person to attempt to devise a system of classification based on morphology and anatomy. He placed organisms in a hierarchy according to the complexity of their structure and function. Indeed, some of his ideas still existed just 200 years ago. He separated animals into two groups: those with blood and those without, placing invertebrates into the second group and vertebrates into the first. However, he was not aware that some invertebrates do have a form of haemoglobin. Using blood as a common feature would put earthworms and humans in the same group! Earthworm blood is red: it contains haemoglobin, although it is not contained in red blood cells.

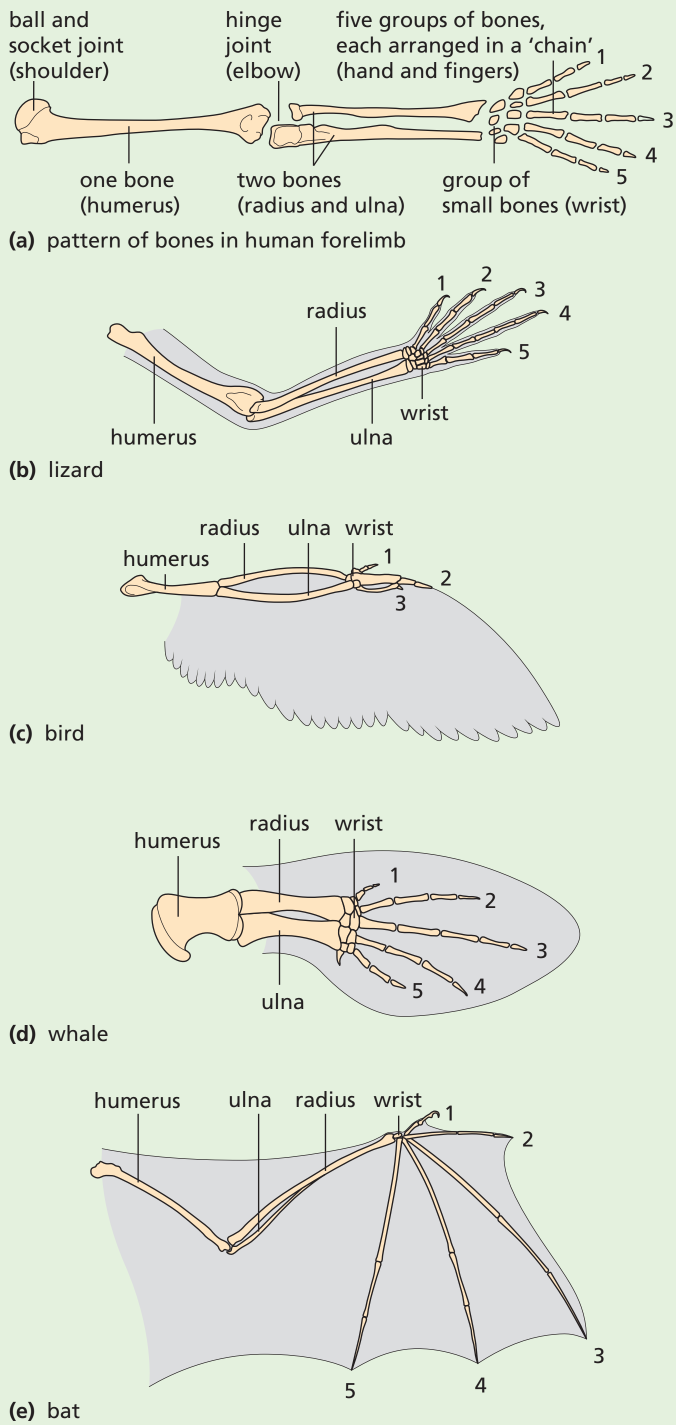


Figure 1.3 Skeletons of five vertebrate limbs

Plants have been classified according to their morphology, but appearances can be deceptive. The London Plane tree and the British Sycamore were considered to be closely related because of the similarity in their leaf shape, as shown in Figure 1.4.

Figure 1.4 Leaves of the British Sycamore (left) and London Plane (right)

However, a closer study of the two species exposes major differences: leaf insertion (how they are arranged on a branch) in London Plane is alternate, while it is opposite in the Sycamore. Also, their fruits are very different, as shown in Figure 1.5.

Figure 1.5 Fruits of the British Sycamore (left) and London Plane (right)

The scientific name of the London Plane is *Platanus acerifolia* (meaning 'leaves like an Acer'); that of the British Sycamore is *Acer pseudoplatanus* ('pseudo' means 'false'). They do not even belong in the same genus.

The use of **DNA** has revolutionised the process of classification. Eukaryotic organisms contain chromosomes made up of strings of genes. The chemical which forms these genes is called DNA (which is short for deoxyribonucleic acid). The DNA is made up of a sequence of bases, coding for amino acids and, therefore, proteins (see Chapters 4 and 17). Each species has a distinct number of chromosomes and a unique sequence of bases in its DNA, making it identifiable and distinguishable from other species. This helps particularly when different species are very similar morphologically (in appearance) and anatomically (in internal structure).

The process of biological classification called **cladistics** involves organisms being grouped together according to whether or not they have one or more shared unique characteristics derived from the group's last common ancestor, which are not present in more distant ancestors. Organisms which share a more recent ancestor (and are, therefore, more closely related) have DNA base sequences that are more similar than those that share only a distant ancestor.

Human and primate evolution is a good example of how DNA has been used to clarify a process of evolution. Traditional classification of primates (into monkeys, apes and humans) was based on their anatomy, particularly their bones and teeth. This put humans on a separate branch, while grouping the other apes together into one family called Pongidae.

However, genetic evidence using DNA provides a different insight – humans are more closely related to chimpanzees (1.2% difference in the genome – the complete set of genetic material of the organism) and gorillas (1.6% different) than to orang-utans (3.1% different). Also, chimpanzees are closer to humans than to gorillas (see Figure 1.6).

Bonobos and chimps are found in Zaire and were only identified as different species in 1929. The two species share the same percentage difference in the genome from humans.

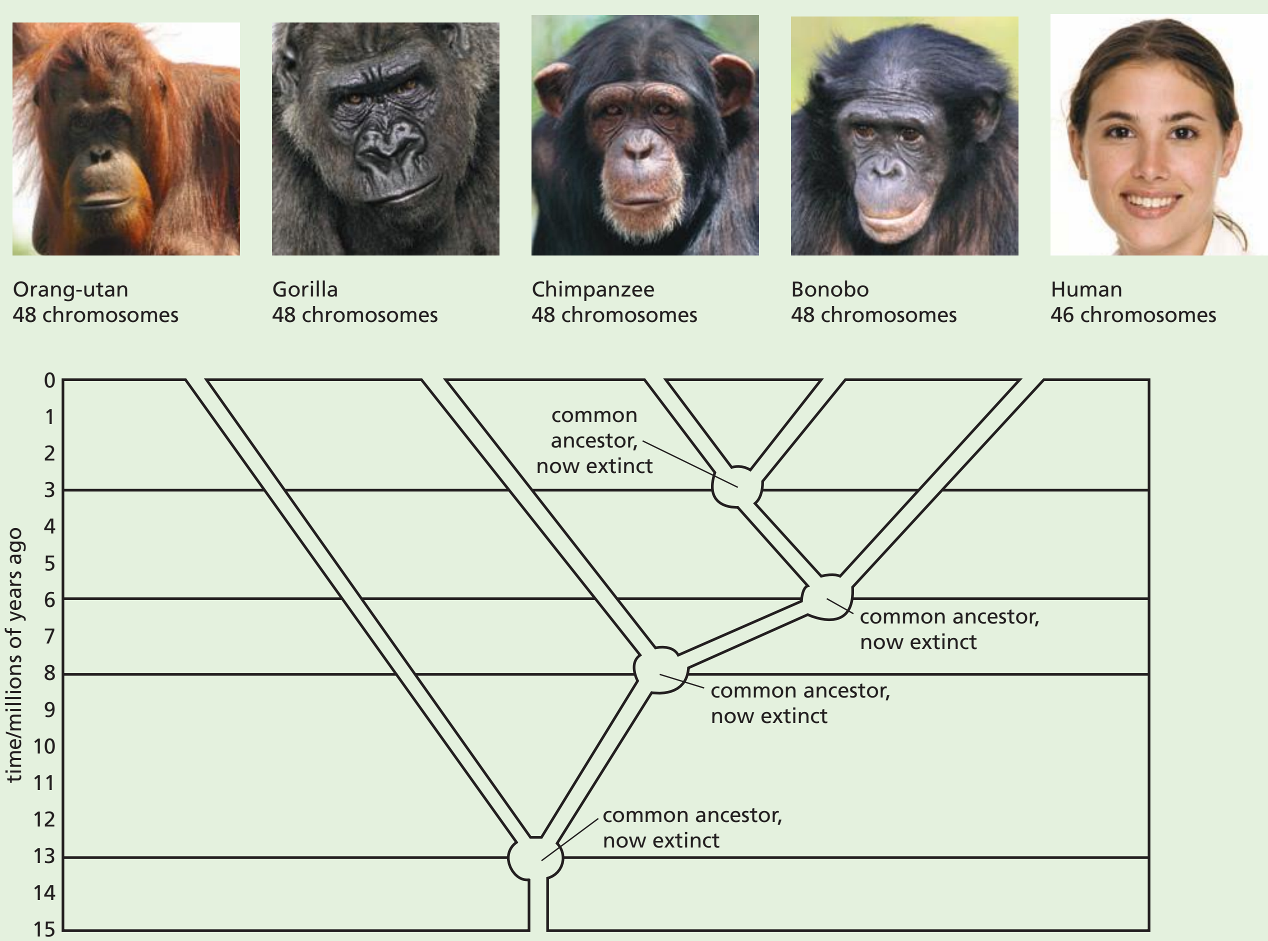


Figure 1.6 Classification of primates, based on DNA evidence

Features of organisms

All living organisms have certain features in common, including the presence of cytoplasm and cell membranes, and DNA as genetic material.

All living organisms also contain **ribosomes** in the cytoplasm, floating freely or attached to membranes called **rough endoplasmic reticulum** (ER). Ribosomes are responsible for protein synthesis.

The Whittaker five-kingdom scheme

The largest group of organisms recognised by biologists is the kingdom. But how many kingdoms should there be? Most biologists used to favour the adoption of two kingdoms, namely **Plants** and **Animals**. This, however, caused problems in trying to classify fungi, bacteria and single-celled organisms which do not fit obviously into either kingdom. A scheme now favoured by many biologists is the Whittaker five-kingdom scheme consisting of **Animal**, **Plant**, **Fungus**, **Prokaryote** and **Protoctist**.

It is still not easy to fit all organisms into the five-kingdom scheme. For example, many protoctista with chlorophyll (the protophyta) show important resemblances to some members of the algae, but the algae are classified into the plant kingdom.

Viruses are not included in any kingdom – they are not considered to be living organisms because they lack cell membranes (made of protein and lipid), cytoplasm and ribosomes and do not demonstrate the characteristics of living things: they do not feed, respire, excrete or grow. Although viruses do reproduce, this only happens inside the cells of living organisms, using materials provided by the host cell.

This kind of problem will always occur when we try to devise rigid classification schemes with distinct boundaries between groups. The process of evolution would hardly be expected to result in a tidy scheme of classification for biologists to use.

Extension work

As scientists learn more about organisms, classification schemes change. Genetic sequencing has provided scientists with a different way of studying relationships between organisms. The **three-domain scheme** was introduced by Carl Woese in 1978 and involves grouping organisms using differences in ribosomal RNA structure. Under this scheme, organisms are classified into three domains and six kingdoms, rather than five. The sixth kingdom is created by splitting the Prokaryote kingdom into two. The domains are:

1 **Archaea**: containing ancient prokaryotic organisms which do not have a nucleus surrounded by a membrane. They have an independent evolutionary history to other bacteria and their biochemistry is very different to other forms of life.
2 **Eubacteria**: prokaryotic organisms which do not have a nucleus surrounded by a membrane.
3 **Eukarya**: organisms that have a membrane-bound nucleus. This domain is further subdivided into the kingdoms Protoctist, Fungus, Plant and Animal.

A summary of the classification schemes proposed by scientists is shown in Figure 1.7.

A two-kingdom scheme: Linnaeus

Animal	Plant

A five-kingdom scheme: Whittaker

Animal	Plant	Fungus	Prokaryote	Protoctist

A six-kingdom system: Woese

Animal	Plant	Fungus	Eubacteria	Archaebacteria	Protoctist

A three-domain system: Woese

Eubacteria	Archaea	Eukarya

Figure 1.7 A summary of the classification schemes proposed by scientists

An outline classification of plants and animals follows and is illustrated in Figures 1.8–1.11.

The plant kingdom

These are made up of many cells – they are multicellular. Plant cells have an outside wall made of cellulose. Many of the cells in plant leaves and stems contain chloroplasts with photosynthetic pigments, e.g. chlorophyll. Plants make their food by photosynthesis.

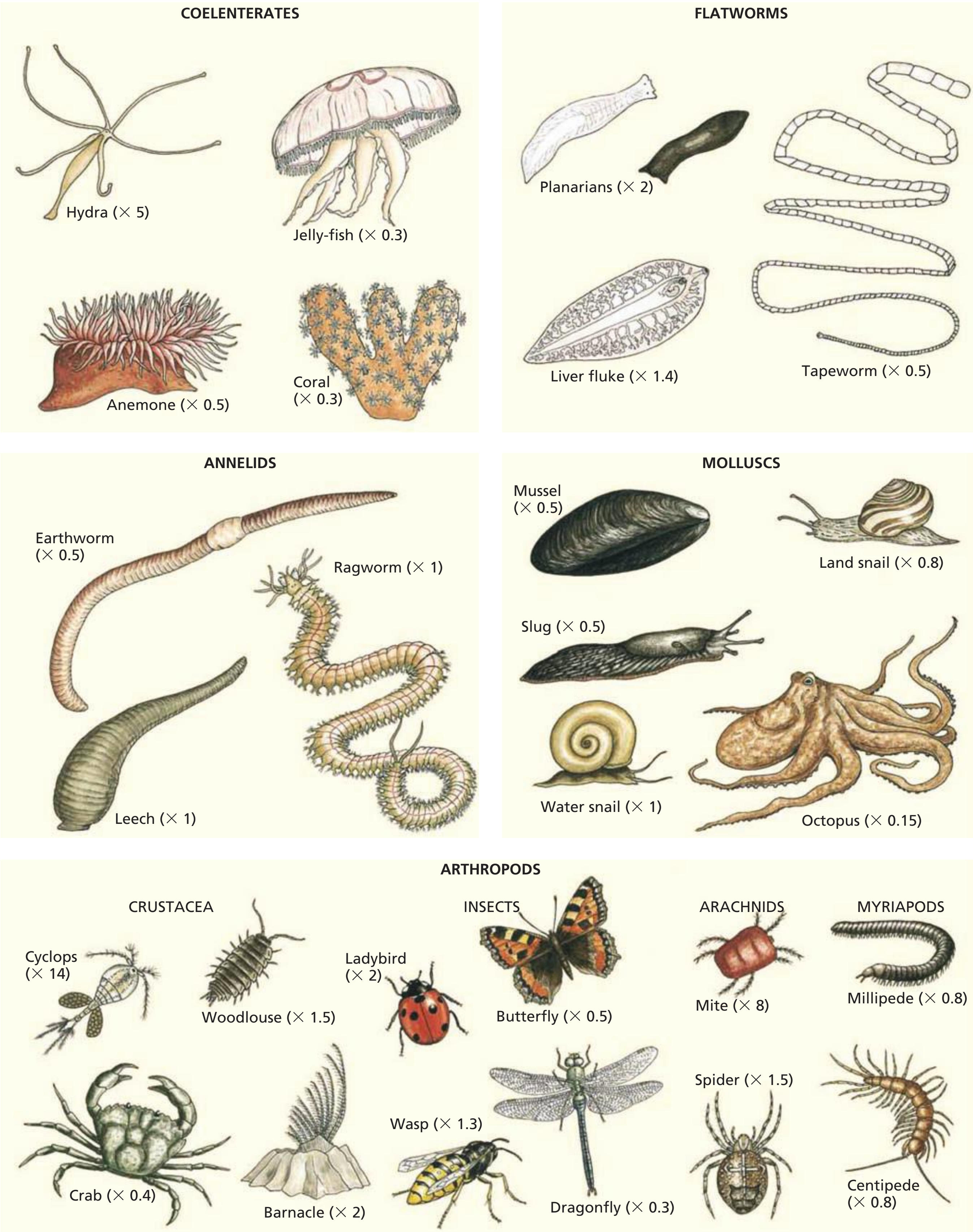


Figure 1.8 The animal kingdom; examples of five invertebrate groups (phyla)

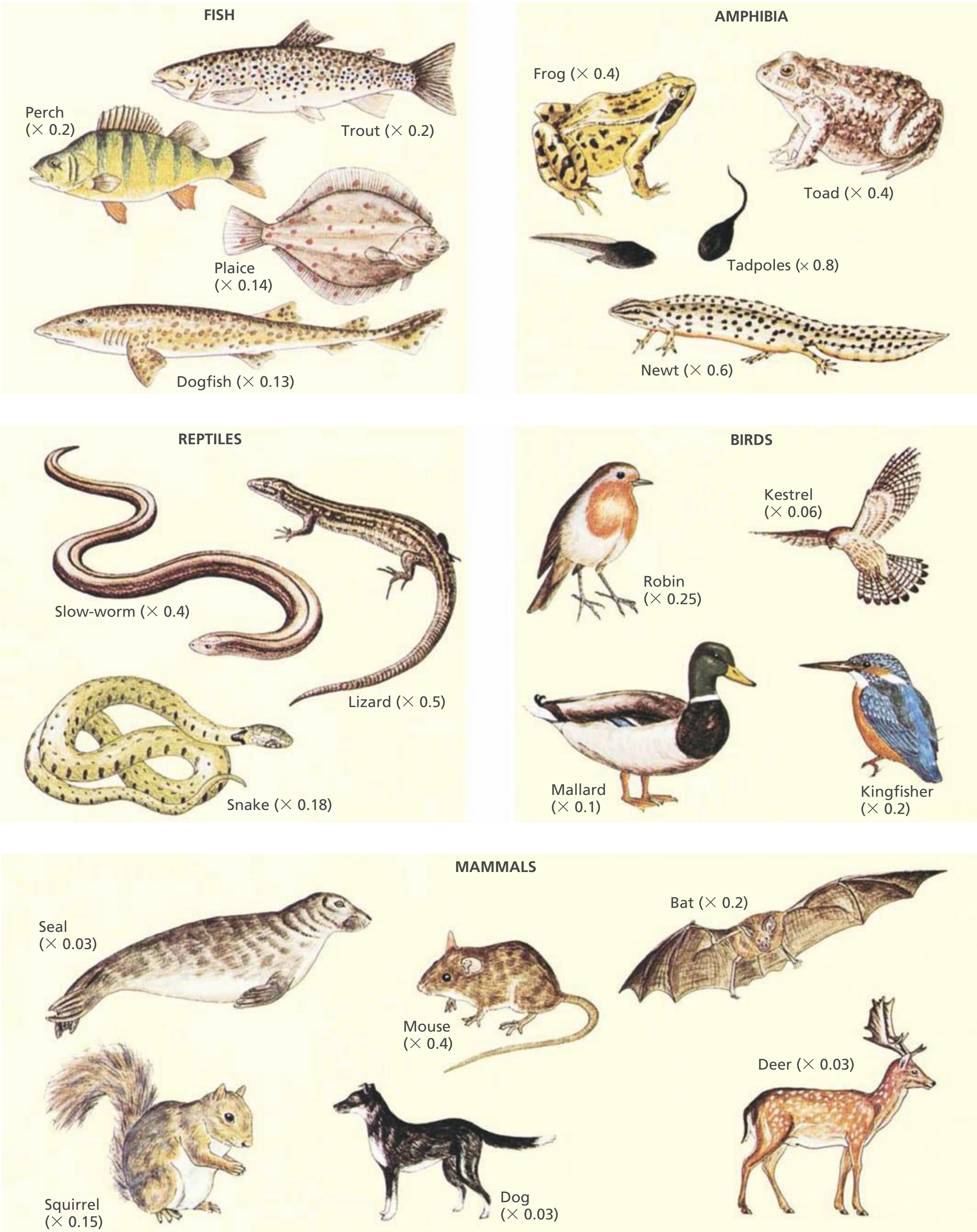


Figure 1.9 The animal kingdom; the vertebrate classes

Figure 1.10 The plant kingdom; plants that do not bear seeds

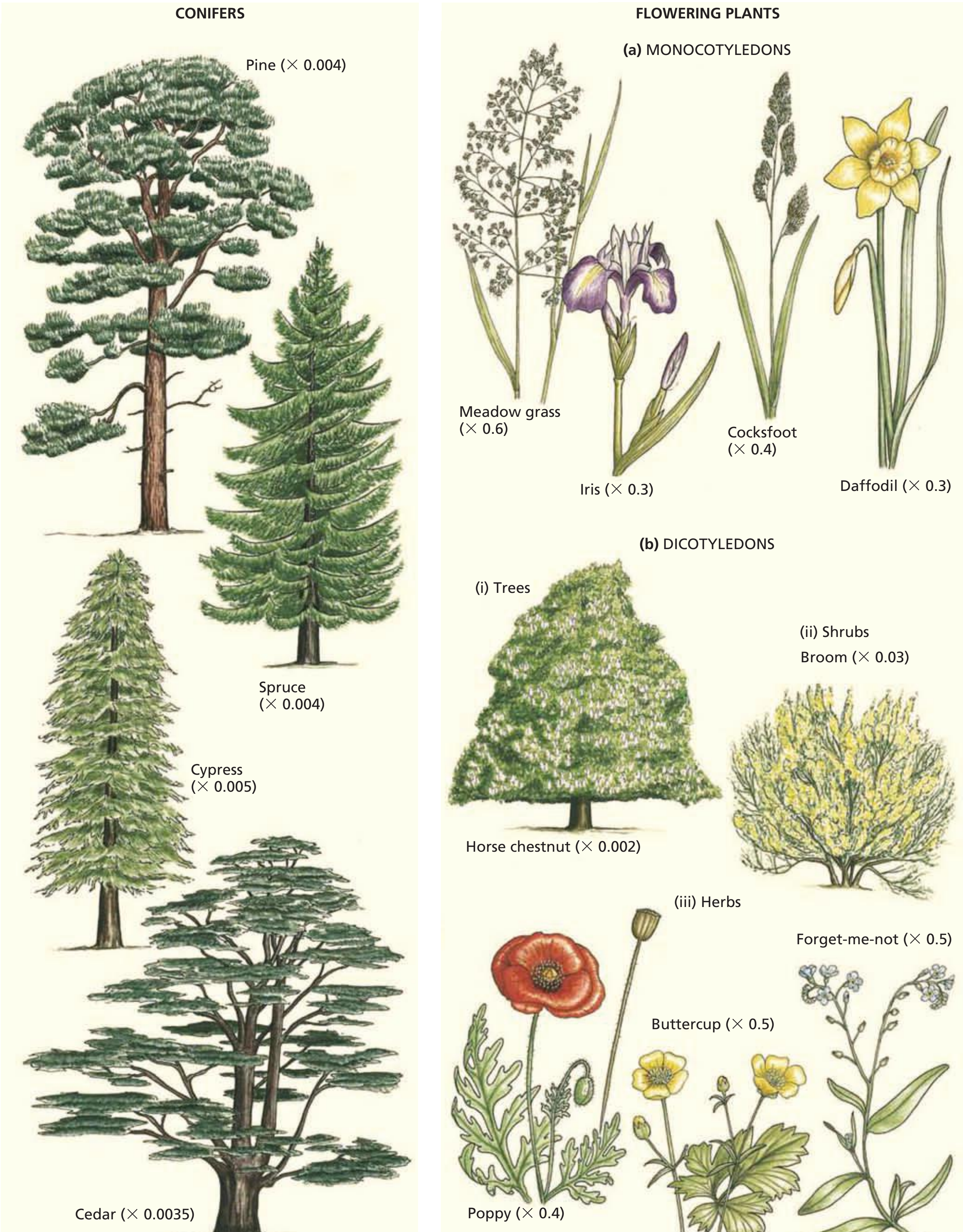


Figure 1.11 The plant kingdom; seed-bearing plants

The animal kingdom

Animals are multicellular organisms whose cells have no cell walls or chloroplasts. Most animals ingest solid food and digest it internally.

Animal kingdom

(Only eight groups out of 23 are listed here.) Each group is called a phylum (plural = phyla).

* {
- **Coelenterates** (sea anemones, jellyfish)
- **Flatworms**
- **Nematode worms**
- **Annelids** (segmented worms)
- **Arthropods**
  - CLASS
  - Crustacea (crabs, shrimps, water fleas)
  - Insects
  - Arachnids (spiders and mites)
  - Myriapods (centipedes and millipedes)
- **Molluscs** (snails, slugs, mussels, octopuses)
- **Echinoderms** (starfish, sea urchins)

}

- **Vertebrates**
  - CLASS
  - Fish
  - Amphibia (frogs, toads, newts)
  - Reptiles (lizards, snakes, turtles)
  - Birds
  - Mammals
  - (Only four subgroups out of about 26 are listed.)
    - Insectivores
    - Carnivores
    - Rodents
    - Primates

*All the organisms which do not have a vertebral column are often referred to as invertebrates. Invertebrates are not a natural group, but the term is convenient to use.

Arthropods

The arthropods include the crustacea, insects, centipedes and spiders (see Figure 1.8 on page 7). The name arthropod means 'jointed limbs', and this is a feature common to them all. They also have a hard, firm external skeleton, called a **cuticle**, which encloses their bodies. Their bodies are segmented and, between the segments, there are flexible joints which permit movement. In most arthropods, the segments are grouped together to form distinct regions, the head, thorax and abdomen. Table 1.1 outlines the key features of the four classes of arthropod.

Crustacea

Marine crustacea are crabs, prawns, lobsters, shrimps and barnacles. Freshwater crustacea are water fleas, *Cyclops*, the freshwater shrimp (*Gammarus*) and the water louse (*Asellus*). Woodlice are land-dwelling crustacea. Some of these crustacea are illustrated in Figure 1.8 on page 7.

Like all arthropods, crustacea have an exoskeleton and jointed legs. They also have two pairs of antennae which are sensitive to touch and to chemicals, and they have **compound eyes**. Compound eyes are made up of tens or hundreds of separate lenses with light-sensitive cells beneath. They are able to form a crude image and are very sensitive to movement.

Typically, crustacea have a pair of jointed limbs on each segment of the body, but those on the head segments are modified to form antennae or specialised mouth parts for feeding (see Figure 1.12).

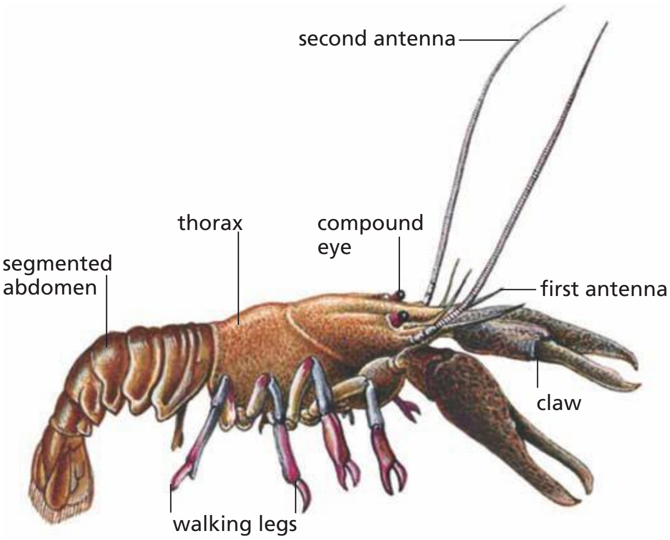


Figure 1.12 External features of a crustacean (lobster ×0.2)

Insects

The insects form a very large class of arthropods. Bees, butterflies, mosquitoes, houseflies, earwigs, greenfly and beetles are just a few of the subgroups in this class.

Insects have segmented bodies with a firm exoskeleton, three pairs of jointed legs, compound eyes and, typically, two pairs of wings. The segments are grouped into distinct head, thorax and abdomen regions (see Figure 1.13).

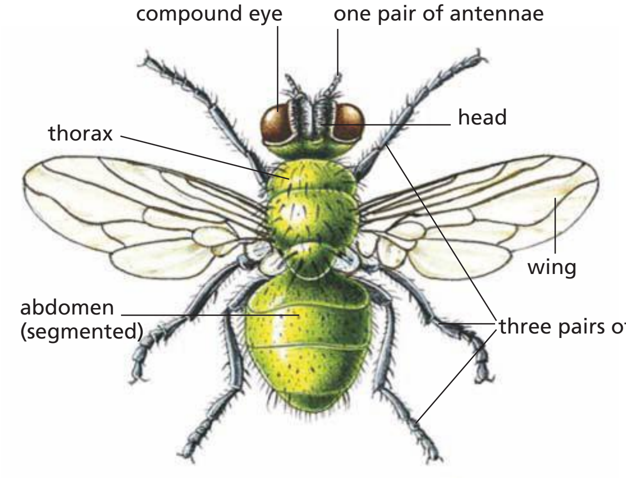


Figure 1.13 External features of an insect (greenbottle, ×5). Flies, midges and mosquitoes have only one pair of wings.

Insects differ from crustacea in having wings, only one pair of antennae and only three pairs of legs. There are no limbs on the abdominal segments.

The insects have very successfully colonised the land. One reason for their success is the relative impermeability of their cuticles, which prevents desiccation even in very hot, dry climates.

Arachnids

These are the spiders, scorpions, mites and ticks. Their bodies are divided into two regions, the cephalothorax and the abdomen (see Figure 1.14). They have four pairs of limbs on the cephalothorax, two pedipalps and two chelicerae. The pedipalps are used in reproduction; the chelicerae are used to pierce their prey and paralyse it with a poison secreted by a gland at the base. There are usually several pairs of simple eyes.

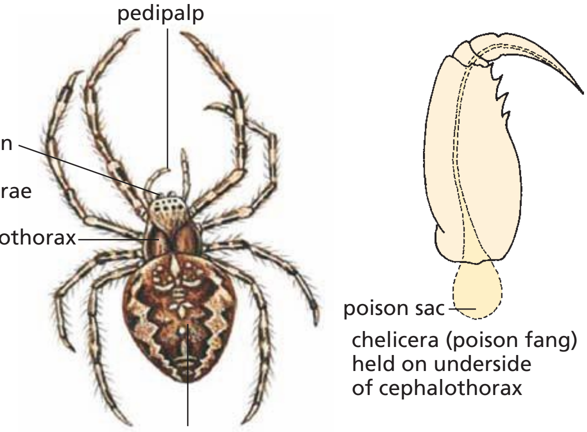


Figure 1.14 External features of an arachnid (×2.5)

Myriapods

These are millipedes and centipedes. They have a head and a segmented body which is not obviously divided into thorax and abdomen. There is a pair of legs on each body segment but in the millipede the abdominal segments are fused in pairs and it looks as if it has two pairs of legs per segment (see Figure 1.15).

As the myriapod grows, additional segments are formed. The myriapods have one pair of antennae and simple eyes. Centipedes are carnivorous; millipedes feed on vegetable matter.

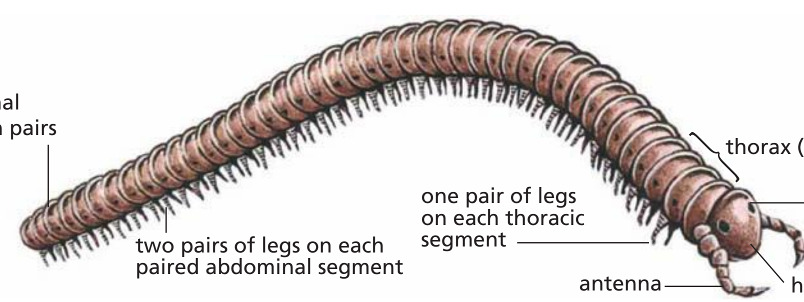


Figure 1.15 External features of a myriapod (×2.5)

Table 1.1 Key features of the four classes of arthropods

Insects	Arachnids	Crustacea	Myriapods
e.g. dragonfly, wasp	e.g. spider, mite	e.g. crab, woodlouse	e.g. centipede, millipede
• three pairs of legs	• four pairs of legs	• five or more pairs of legs	• ten or more pairs of legs (usually one pair per segment)
• body divided into head, thorax and abdomen	• body divided into cephalothorax and abdomen	• body divided into cephalothorax and abdomen	• body not obviously divided into thorax and abdomen
• one pair of antennae		• two pairs of antennae	• one pair of antennae
• one pair of compound eyes	• several pairs of simple eyes	• one pair of compound eyes	• simple eyes
• usually have two pairs of wings	• chelicerae for biting and poisoning prey	• exoskeleton often calcified to form a carapace (hard)	

Vertebrates

Vertebrates are animals which have a vertebral column. The vertebral column is sometimes called the spinal column or just the spine and consists of a chain of cylindrical bones (vertebrae) joined end to end.

Each vertebra carries an arch of bone on its dorsal (upper) surface. This arch protects the spinal cord (see Chapter 14), which runs most of the length of the vertebral column. The front end of the spinal cord is expanded to form a brain which is enclosed and protected by the skull.

The skull carries a pair of jaws which, in most vertebrates, have rows of teeth.

The five classes of vertebrates are fish, amphibia, reptiles, birds and mammals. Table 1.2 summarises the key features of these classes.

Body temperature

Fish, amphibia and reptiles are often referred to as 'cold-blooded'. This is a misleading term. A fish in a tropical lagoon or a lizard basking in the sun will have warm blood. The point is that these animals have a variable body temperature which, to some extent, depends on the temperature of their surroundings. Reptiles, for example, may control their temperature by moving into sunlight or retreating into shade but there is no internal regulatory mechanism.

So-called 'warm-blooded' animals, for the most part, have a body temperature higher than that of their surroundings. The main difference, however, is that these temperatures are kept more or less constant despite any variation in external temperature. There are internal regulatory mechanisms (see Chapter 14) which keep the body temperature within narrow limits.

It is better to use the terms **poikilothermic** (variable temperature) and **homoiothermic** (constant temperature). However, to simplify the terms, 'cold blooded' and 'warm blooded' will be referred to in this section.

The advantage of homoiothermy is that an animal's activity is not dependent on the surrounding temperature. A lizard may become sluggish if the surrounding temperature falls. This could be a disadvantage if the lizard is being pursued by a homoiothermic predator whose speed and reactions are not affected by low temperatures.

Fish

Fish are poikilothermic (cold blooded) vertebrates. Many of them have a smooth, streamlined shape which offers minimal resistance to the water through which they move (see Figure 1.16). Their bodies are covered with overlapping scales and they have fins which play a part in movement.

Fish breathe by means of filamentous gills which are protected by a bony plate, the operculum.

Fish reproduce sexually but fertilisation usually takes place externally; the female lays eggs and the male sheds sperms on them after they have been laid.

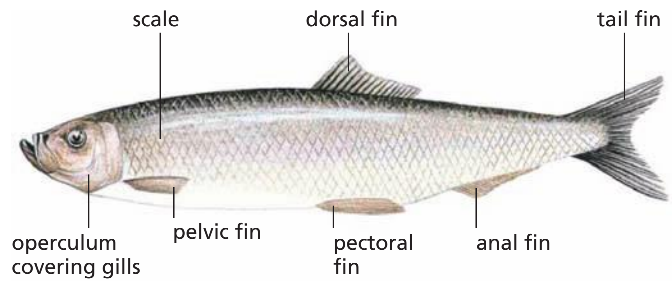


Figure 1.16 Herring (*Clupea*, ×0.3)

Amphibia

Amphibia are poikilothermic (cold blooded) vertebrates with four limbs and no scales. The class includes frogs, toads and newts. The name, amphibian, means 'double life' and refers to the fact that the organism spends part of its life in water and part on the land. In fact, most frogs, toads and newts spend much of their time on the land, in moist situations, and return to ponds or other water only to lay eggs.

The external features of the common frog are shown in Figure 1.17. Figure 1.9 on page 8 shows the toad and the newt.

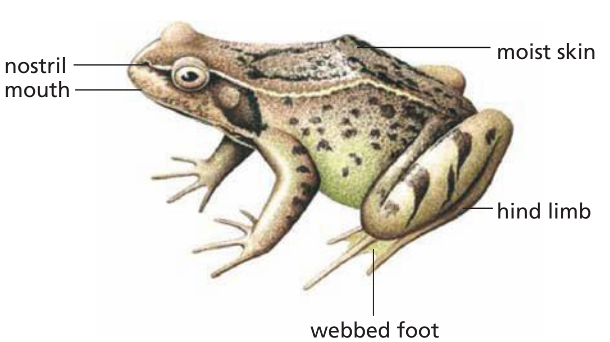


Figure 1.17 *Rana* (×0.75)

The toad's skin is drier than that of the frog and it has glands which can exude an unpleasant-tasting chemical which discourages predators. Newts differ from frogs and toads in having a tail. All three groups are carnivorous.

Amphibia have four limbs. In frogs and toads, the hind feet have a web of skin between the toes. This offers a large surface area to thrust against the water when the animal is swimming. Newts swim by a wriggling, fish-like movement of their bodies and make less use of their limbs for swimming.

Amphibia have moist skins with a good supply of capillaries which can exchange oxygen and carbon dioxide with the air or water. They also have lungs which can be inflated by a kind of swallowing action. They do not have a diaphragm or ribs.

Frogs and toads migrate to ponds where the males and females pair up. The male climbs on the female's back and grips firmly with his front legs (see Figure 1.18). When the female lays eggs, the male simultaneously releases sperms over them. Fertilisation, therefore, is external even though the frogs are in close contact for the event.

Figure 1.18 Frogs pairing. The male clings to the female's back and releases his sperm as she lays the eggs.

Reptiles

Reptiles are land-living vertebrates. Their skins are dry and the outer layer of epidermis forms a pattern of scales. This dry, scaly skin resists water loss. Also the eggs of most species have a tough, parchment-like shell. Reptiles, therefore, are not restricted to damp habitats, nor do they need water in which to breed.

Reptiles are poikilothermic (cold blooded) but they can regulate their temperature to some extent. They do this by basking in the sun until their bodies warm up. When reptiles warm up, they can move about rapidly in pursuit of insects and other prey.

The reptiles include lizards, snakes, turtles, tortoises and crocodiles (see Figure 1.19 and Figure 1.9 on page 8).

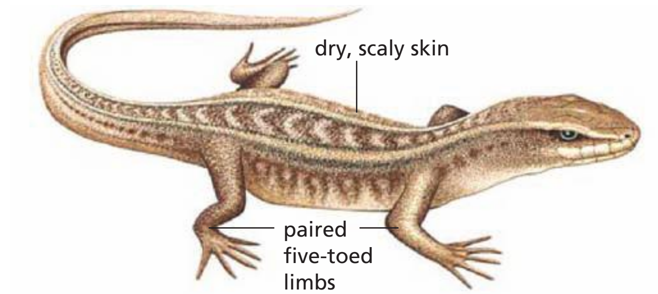


Figure 1.19 *Lacerta* (×1.5)

Apart from the snakes, reptiles have four limbs, each with five toes. Some species of snake still retain the vestiges of limbs and girdles.

Male and female reptiles mate, and sperms are passed into the female's body. The eggs are, therefore, fertilised internally before being laid. In some species, the female retains the eggs in the body until they are ready to hatch.

Birds

Birds are homoiothermic (warm blooded) vertebrates.

The vertebral column in the neck is flexible but the rest of the vertebrae are fused to form a rigid structure. This is probably an adaptation to flight, as the powerful wing muscles need a rigid frame to work against.

The epidermis over most of the body produces a covering of feathers but, on the legs and toes, the epidermis forms scales. The feathers are of several kinds. The fluffy down feathers form an insulating layer close to the skin; the contour feathers cover the body and give the bird its shape and colouration; the large quill feathers on the wing are essential for flight.

Birds have four limbs, but the forelimbs are modified to form wings. The feet have four toes with claws which help the bird to perch, scratch for seeds or capture prey, according to the species.

The upper and lower jaws are extended to form a beak which is used for feeding in various ways.

Figure 1.20 shows the main features of a bird.

In birds, fertilisation is internal and the female lays hard-shelled eggs in a nest where she incubates them.

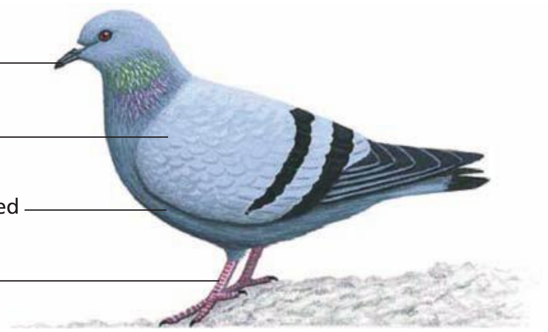


Figure 1.20 The main features of a pigeon (×0.14)

Mammals

Mammals are homoiothermic (warm blooded) vertebrates with four limbs. They differ from birds in having hair rather than feathers. Unlike the other vertebrates they have a diaphragm which plays a part in breathing (see Chapter 11). They also have mammary glands and suckle their young on milk.

A sample of mammals is shown in Figure 1.9 on page 8 and Figure 1.21 illustrates some of the mammalian features.

Humans are mammals. All mammals give birth to fully formed young instead of laying eggs. The eggs are fertilised internally and undergo a period of development in the uterus (see 'Sexual reproduction in humans' in Chapter 16).

Figure 1.21 Mammalian features. The furry coat, the external ear pinnae and the facial whiskers (vibrissae) are visible mammalian features in this gerbil.

The young may be blind and helpless at first, e.g. cats, or they may be able to stand up and move about soon after birth, e.g. sheep and cows. In either case, the youngster's first food is the milk which it sucks from the mother's teats. The milk is made in the mammary glands and contains all the nutrients that the offspring need for the first few weeks or months, depending on the species.

As the youngsters get older, they start to feed on the same food as the parents. In the case of carnivores, the parents bring the food to the young until they are able to fend for themselves.

Table 1.2 Key features of the five classes of vertebrates

Vertebrate class	Fish	Amphibia	Reptiles	Birds	Mammals
Examples	herring, perch, also sharks	frog, toad, newt	lizard, snake	robin, pigeon	mouse
Body covering	scales	moist skin	dry skin, with scales	feathers, with scales on legs	fur
Movement	fins (also used for balance)	four limbs, back feet are often webbed to make swimming more efficient	four legs (apart from snakes)	two wings and two legs	four limbs
Reproduction	produce jelly-covered eggs in water	produce jelly-covered eggs in water	produce eggs with a rubbery, waterproof shell; laid on land	produce eggs with a hard shell; laid on land	produce live young
Sense organs	eyes; no ears; lateral line along body for detecting vibrations in water	eyes; ears	eyes; ears	eyes; ears	eyes; ears with a pinna (external flap)
Other details	cold blooded; gills for breathing	cold blooded; lungs and skin for breathing	cold blooded; lungs for breathing	warm blooded; lungs for breathing; beak	warm blooded; lungs for breathing; females have mammary glands to produce milk to feed young; four types of teeth

The plant kingdom

It is useful to have an overview of the classification of the plant kingdom, although only two groups (ferns and flowering plants) will be tested in the examination.

Plant kingdom

DIVISION

Red algae
Brown algae
Green algae
} seaweeds and filamentous forms; mostly aquatic

Bryophytes (no specialised conducting tissue)

CLASS
Liverworts
Mosses

Vascular plants (well-developed xylem and phloem)

CLASS
Ferns
{Conifers (seeds not enclosed in fruits)
Flowering plants (seeds enclosed in fruits)} Sometimes called, collectively, 'seed-bearing plants'

SUBCLASS
Monocotyledons (grasses, lilies)
Dicotyledons (trees, shrubs, herbaceous plants)

FAMILY
e.g. Ranunculaceae (one of about 70 families)

GENUS
e.g. *Ranunculus*

SPECIES
e.g. *Ranunculus bulbosus*
(bulbous buttercup)

Ferns

Ferns are land plants with quite highly developed structures. Their stems, leaves and roots are very similar to those of the flowering plants.

The stem is usually entirely below ground and takes the form of a structure called a **rhizome**. In bracken, the rhizome grows horizontally below ground, sending up leaves at intervals. The roots which grow from the rhizome are called adventitious roots (see 'Transport in plants' in Chapter 8). This is the name given to any roots which grow directly from the stem rather than from other roots.

The stem and leaves have sieve tubes and water-conducting cells similar to those in the xylem and phloem of a flowering plant (see Chapter 8). For this reason, the ferns and seed-bearing plants are sometimes referred to as vascular plants, because they all have vascular bundles or vascular tissue. Ferns also have multicellular roots with vascular tissue.

The leaves of ferns vary from one species to another (see Figure 1.22, and Figure 1.10 on page 9), but they are all several cells thick. Most of them have an upper and lower epidermis, a layer of palisade cells and a spongy mesophyll similar to the leaves of a flowering plant.

Figure 1.22 Young fern leaves. Ferns do not form buds like those of the flowering plants. The midrib and leaflets of the young leaf are tightly coiled and unwind as it grows.

Ferns produce gametes but no seeds. The zygote gives rise to the fern plant, which then produces single-celled spores from numerous **sporangia** (spore capsules) on its leaves. The sporangia are formed on the lower side of the leaf but their position depends on the species of fern. The sporangia are usually arranged in compact groups (see Figure 1.23).

Figure 1.23 Polypody fern. Each brown patch on the underside of the leaf is made up of many sporangia.

Flowering plants

Flowering plants reproduce by seeds which are formed in flowers. The seeds are enclosed in an ovary. The general structure of flowering plants is described in Chapter 8. Examples are shown in Figure 1.11 on page 10. Flowering plants are divided into two subclasses: monocotyledons and dicotyledons. Monocotyledons (monocots for short), are flowering plants which have only one cotyledon in their seeds. Most, but not all, monocots also have long, narrow leaves (e.g. grasses, daffodils, bluebells) with parallel leaf veins (see Figure 1.24(a)).

The dicotyledons (dicots for short), have two cotyledons in their seeds. Their leaves are usually broad and the leaf veins form a branching network (see Figure 1.24(b)).

The key features of monocots and dicots are summarised in Table 1.3.

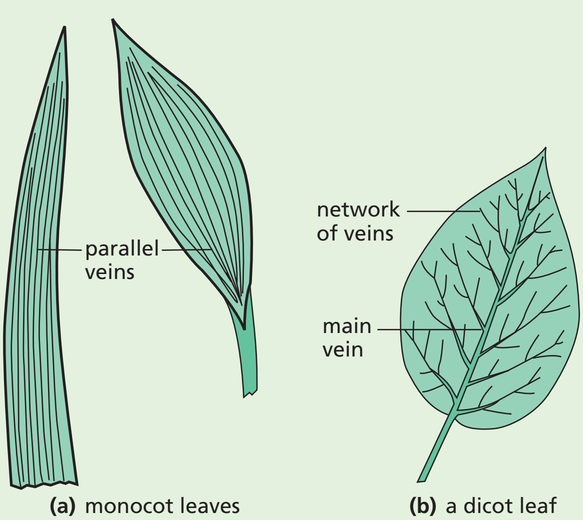


Figure 1.24 Leaf types in flowering plants

Table 1.3 Summary of the key features of monocots and dicots

Feature	Monocotyledon	Dicotyledon
leaf shape	long and narrow	broad
leaf veins	parallel	branching
cotyledons	one	two
grouping of flower parts (petals, sepals and carpels)	threes	fives

In addition to knowing the features used to place animals and plants into the appropriate kingdoms, you also need to know the main features of the following kingdoms: Fungus, Prokaryote and Protoctist.

The fungi kingdom

Most fungi are made up of thread-like hyphae (see Figure 1.25), rather than cells, and there are many nuclei distributed throughout the cytoplasm in their hyphae (see Figure 1.26).

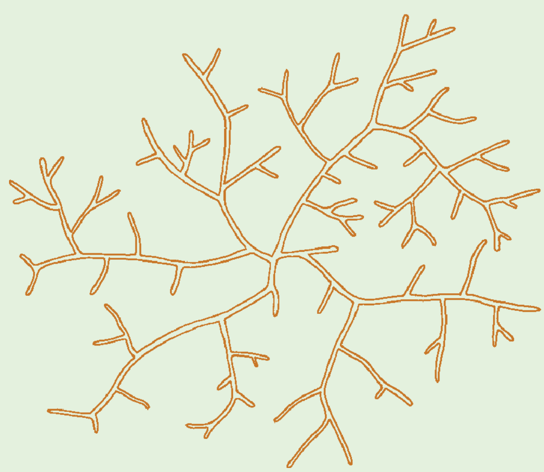


Figure 1.25 The branching hyphae form a mycelium.

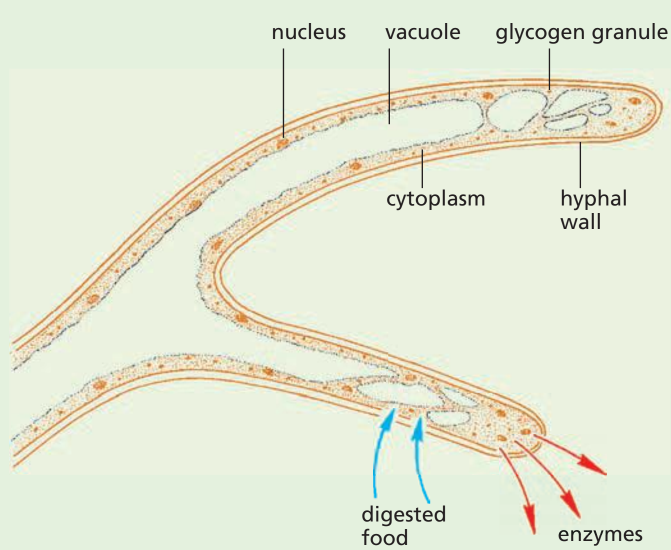


Figure 1.26 The structure of fungal hyphae

The fungi include fairly familiar organisms such as mushrooms, toadstools, puffballs and the bracket fungi that grow on tree trunks (Figure 1.27). There are also the less obvious, but very important, mould fungi which grow on stale bread, cheese, fruit or other food. Many of the mould fungi live in the soil or in dead wood. The yeasts are single-celled fungi similar to the moulds in some respects.

Some fungal species are parasites, as is the bracket fungus shown in Figure 1.27. They live in other organisms, particularly plants, where they cause diseases which can affect crop plants, such as the mildew shown in Figure 1.28. (See also Chapter 10.)

Figure 1.27 A parasitic fungus. The 'brackets' are the reproductive structures. The mycelium in the trunk will eventually kill the tree.

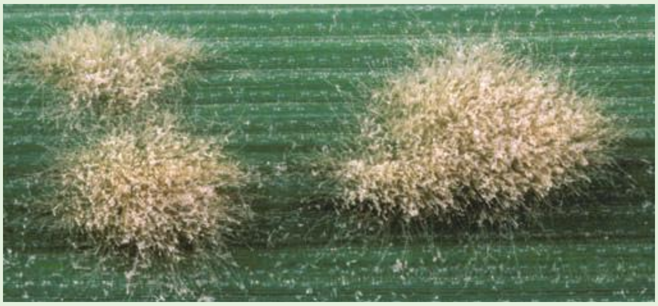


Figure 1.28 Mildew on wheat. Most of the hyphae are inside the leaves, digesting the cells, but some grow out and produce the powdery spores seen here.

The Prokaryote kingdom

These are the bacteria and the blue-green algae. They consist of single cells but differ from other single-celled organisms because their chromosomes are not organised into a nucleus.

Bacterial structure

Bacteria (singular: bacterium) are very small organisms consisting of single cells rarely more than 0.01 mm in length. They can be seen only with the higher powers of the microscope.

Their cell walls are made, not of cellulose, but of a complex mixture of proteins, sugars and lipids. Some bacteria have a **slime capsule** outside their cell wall. Inside the cell wall is the cytoplasm, which may contain granules of glycogen, lipid and other food reserves (see Figure 1.29).

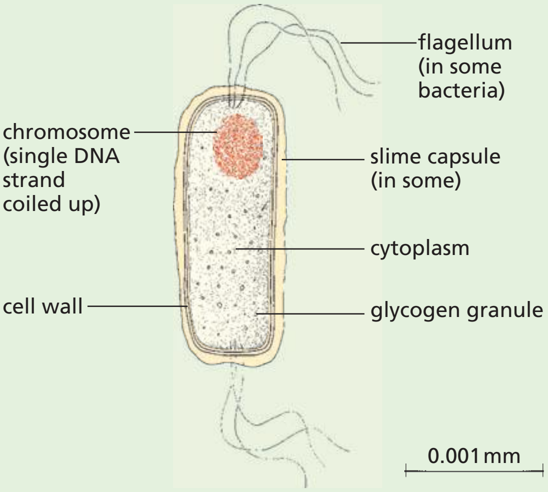


Figure 1.29 Generalised diagram of a bacterium

Each bacterial cell contains a single chromosome, consisting of a circular strand of DNA (see Chapter 4 and 'Chromosomes, genes and proteins' in Chapter 17). The chromosome is not enclosed in a nuclear membrane but is coiled up to occupy part of the cell, as shown in Figure 1.30.

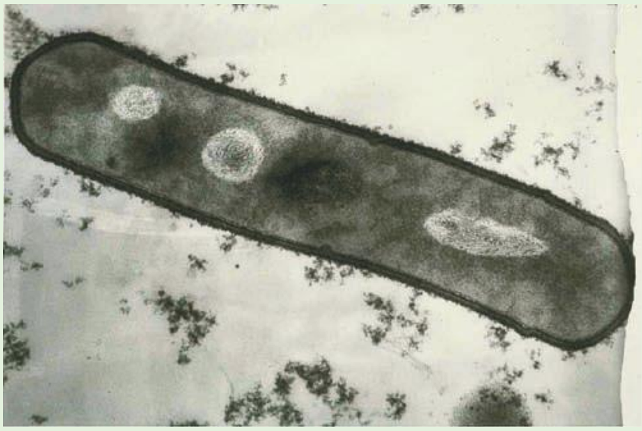


Figure 1.30 Longitudinal section through a bacterium (×27 000). The light areas are coiled DNA strands. There are three of them because the bacterium is about to divide twice (see Figure 1.31).

Individual bacteria may be spherical, rod-shaped or spiral and some have filaments, called **flagella**, projecting from them. The flagella can flick and so move the bacterial cell about.

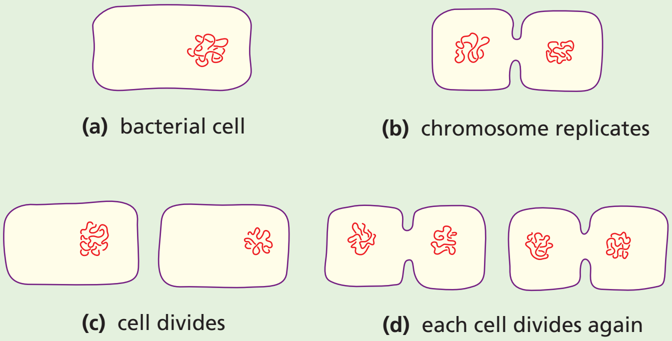


Figure 1.31 Bacterium reproducing. This is asexual reproduction by cell division (see 'Asexual reproduction' in Chapter 16 and 'Mitosis' in Chapter 17).

The Protoctist kingdom

These are single-celled (unicellular) organisms which have their chromosomes enclosed in a nuclear membrane to form a nucleus. Some examples are shown in Figure 1.32.

Some of the protoctista, e.g. *Euglena*, possess chloroplasts and make their food by photosynthesis. These protoctista are often referred to as unicellular 'plants' or **protophyta**. Organisms such as *Amoeba* and *Paramecium* take in and digest solid food and thus resemble animals in their feeding. They may be called unicellular 'animals' or **protozoa**.

Amoeba is a protozoan which moves by a flowing movement of its cytoplasm. It feeds by picking up bacteria and other microscopic organisms as it goes. *Vorticella* has a contractile stalk and feeds by creating a current of water with its cilia. The current brings particles of food to the cell. *Euglena* and *Chlamydomonas* have chloroplasts in their cells and feed, like plants, by photosynthesis.

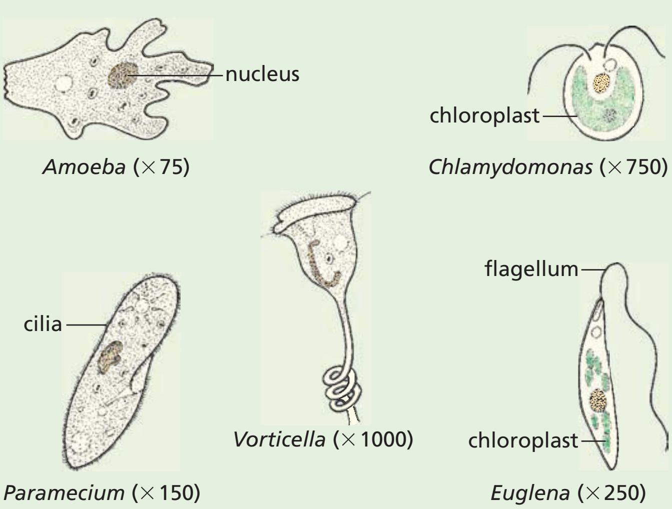


Figure 1.32 Protoctista. *Chlamydomonas* and *Euglena* have chloroplasts and can photosynthesise. The others are protozoa and ingest solid food.

Viruses

There are many different types of virus and they vary in their shape and structure. All viruses, however, have a central core of RNA or DNA (see Chapter 4) surrounded by a protein coat. Viruses have no nucleus, cytoplasm, cell organelles or cell membrane, though some forms have a membrane outside their protein coats.

Virus particles, therefore, are not cells. They do not feed, respire, excrete or grow and it is debatable whether they can be classed as living organisms. Viruses do reproduce, but only inside the cells of living organisms, using materials provided by the host cell.

A generalised virus particle is shown in Figure 1.33. The nucleic acid core is a coiled single strand of RNA. The coat is made up of regularly packed protein units called **capsomeres** each containing many protein molecules. The protein coat is called a **capsid**.

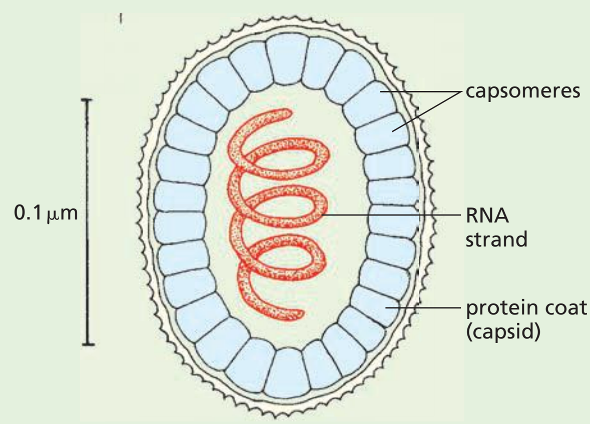


Figure 1.33 Generalised structure of a virus

Extension work

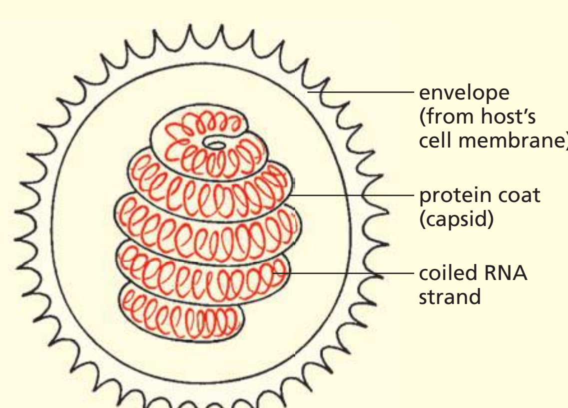


Figure 1.34 Structure of the influenza virus

Outside the capsid, in the influenza virus and some other viruses, is an envelope which is probably derived from the cell membrane of the host cell (Figure 1.34).

Ideas about classification

From the earliest days, humans must have given names to the plants and animals they observed, particularly those that were useful as food or medicine. Over the years, there have been many attempts to sort plants and animals into related groups. Aristotle's 'Ladder of Nature' (Figure 1.35) organised about 500 animal species into broad categories.

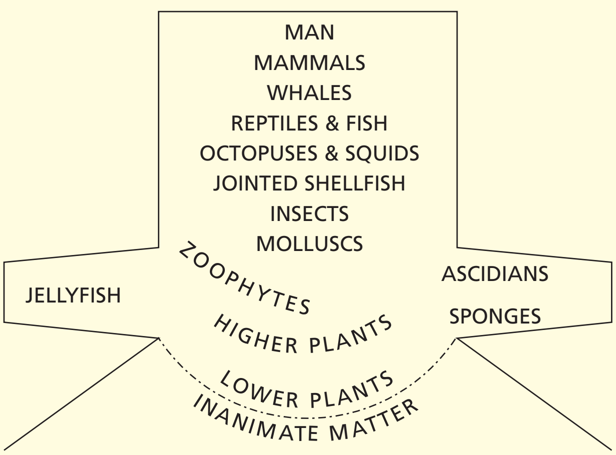


Figure 1.35 Aristotle's 'Ladder of Nature'

The 16th-century herbalists, such as John Gerard, divided the plant world into 'kindes' such as grasses, rushes, grains, irises and bulbs. Categories such as 'medicinal plants' and 'sweet-smelling plants', however, did not constitute a 'natural' classification based on structural features. The herbalists also gave the plants descriptive Latin names, e.g. *Anemone tenuifoliaflorecoccinea* ('the small-leaved scarlet anemone'). The first name shows a recognition of relationship to *Anemone nemorumfloreplenoalbo* ('the double white wood anemone'), for example. This method of naming was refined and popularised by Carl Linnaeus (see below).

John Ray (1625–1705)

Ray was the son of a blacksmith who eventually became a Fellow of the Royal Society. He travelled widely in Britain and Europe making collections of plants, animals and rocks.

In 1667 and 1682 he published a catalogue of British plants based on the structure of their flowers, seeds, fruits and roots. He was the first person to make a distinction between monocots and dicots. Ray also published a classification of animals, based on hooves, toes and teeth. Ultimately he devised classificatory systems for plants, birds, mammals, fish and insects. In doing this, he brought order out of a chaos of names and systems.

At the same time he studied functions, adaptations and behaviour of organisms.

In 1691 he claimed that fossils were the mineralised remains of extinct creatures, possibly from a time when the Earth was supposedly covered by water. This was quite contrary to established (but varied) views on the significance of fossils. Some thought that the fossils grew and developed in the rocks, others supposed that God had put them there 'for his pleasure' and still others claimed that the Devil put them in the rocks to 'tempt, frighten or confuse'. A more plausible theory was that a huge flood had washed marine creatures on to the land.

Despite Ray's declaration, the modern idea of the significance of fossils was not generally accepted until Darwin's day (see 'Selection' in Chapter 18).

Carl Linnaeus (1707–1778)

Linnaeus was a Swedish naturalist who initially graduated in medicine but became interested in plants. He travelled in Scandinavia, England and Eastern Europe, discovering and naming new plant species.

In 1735 he published his *Systema Naturae*, which accurately described about 7700 plant species and classified them, largely on the basis of their reproductive structures (stamens, ovaries, etc., see 'Sexual reproduction in plants' in Chapter 16). He further grouped species into genera, genera into classes, and classes into orders. ('Phyla' came later.) He also classified over 4000 animals, but rather less successfully, into mammals, birds, insects and worms.

Linnaeus refined and popularised the binomial system of naming organisms, in which the first name represents the genus and the second name the species. (See 'Concept and use of a classification system' earlier in this chapter.) This system is still the official starting point for naming or revising the names of organisms.

Although the classificatory system must have suggested some idea of evolution, Linnaeus steadfastly rejected the theory and insisted that no species created by God had ever become extinct.

Dichotomous keys

Dichotomous keys are used to identify unfamiliar organisms. They simplify the process of identification. Each key is made up of pairs of contrasting features (dichotomous means two branches), starting with quite general characteristics and progressing to more specific ones. By following the key and making appropriate choices it is possible to identify the organism correctly.

Figure 1.36 shows an example of a dichotomous key that could be used to place an unknown vertebrate in the correct class. Item 1 gives you a choice between two alternatives. If the animal is poikilothermic (cold blooded), you move to item 2 and make a further choice. If it is homoiothermic (warm blooded), you move to item 4 for your next choice.

The same technique may be used for assigning an organism to its class, genus or species. However, the important features may not always be easy to see and you have to make use of less fundamental characteristics.

VERTEBRATE CLASSES

1	Poikilothermic	2
	Homoiothermic	4
2	Has fins but no limbs	**Fish**
	Has four limbs	3
3	Has no scales on body	**Amphibian**
	Has scales	**Reptile**
4	Has feathers	**Bird**
	Has fur	**Mammal**

Figure 1.36 A dichotomous key for vertebrate classes

Figure 1.37 is a key for identifying some of the possible invertebrates to be found in a compost heap. Of course, you do not need a key to identify these familiar animals but it does show you how a key can be constructed.

You need to be able to develop the skills to construct simple dichotomous keys, based on easily identifiable features. If you know the main characteristics of a group, it is possible to draw up a systematic plan for identifying an unfamiliar organism. One such plan is shown in Figure 1.38 (on the next page).

INHABITANTS OF A COMPOST HEAP

1	Has legs	2
	No legs	5
2	More than six legs	3
	Six legs	4
3	Short, flattened grey body	**Woodlouse**
	Long brown/yellow body	**Centipede**
4	Pincers on last segment	**Earwig**
	Hard wing covers	**Beetle**
5	Body segmented	**Earthworm**
	Body not segmented	6
6	Has a shell	**Snail**
	No shell	**Slug**

Figure 1.37 A dichotomous key for some invertebrates in a compost heap

Figure 1.39 (overleaf) shows five different items of laboratory glassware. If you were unfamiliar with the resources in a science lab you may not be able to name them. We are going to create a dichotomous key to help with identification. All the items have one thing in common – they are made of glass. However, each has features which make it unique and we can devise questions based on these features. The first task is to study the items, to work out what some of them have in common and what makes them different from others. For example, some have a pouring spout, others have graduations marked on the glass for measuring, some have a neck (where the glass narrows to form a thinner structure), some can stand without support because they have a flat base, and so on.

The first question should be based on a feature which will split the group into two. The question is going to generate a 'yes' or 'no' answer. For each of the two sub-groups formed, a further question based on the features of some of that sub-group should then be formulated. Figure 1.40 (overleaf) shows one possible solution.

This is not the only way that a dichotomous key could be devised for the laboratory glassware shown. Construct your own key and test it for each object.

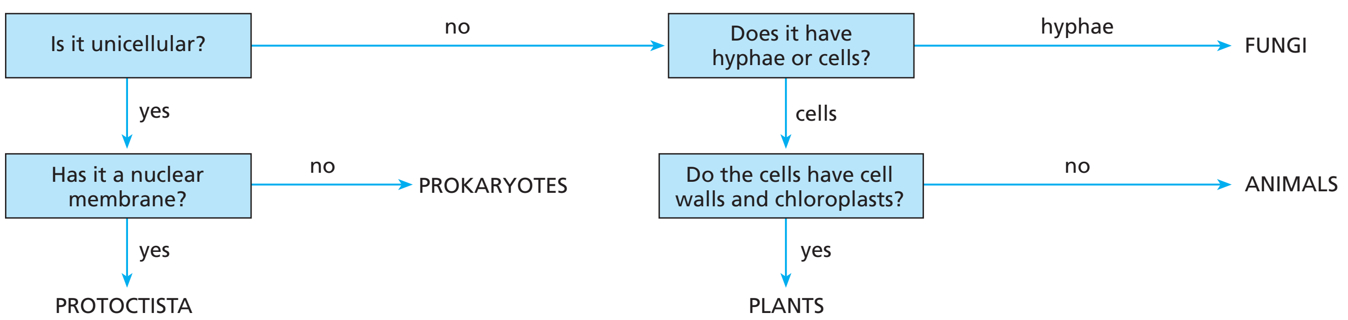


Figure 1.38 Identification plan

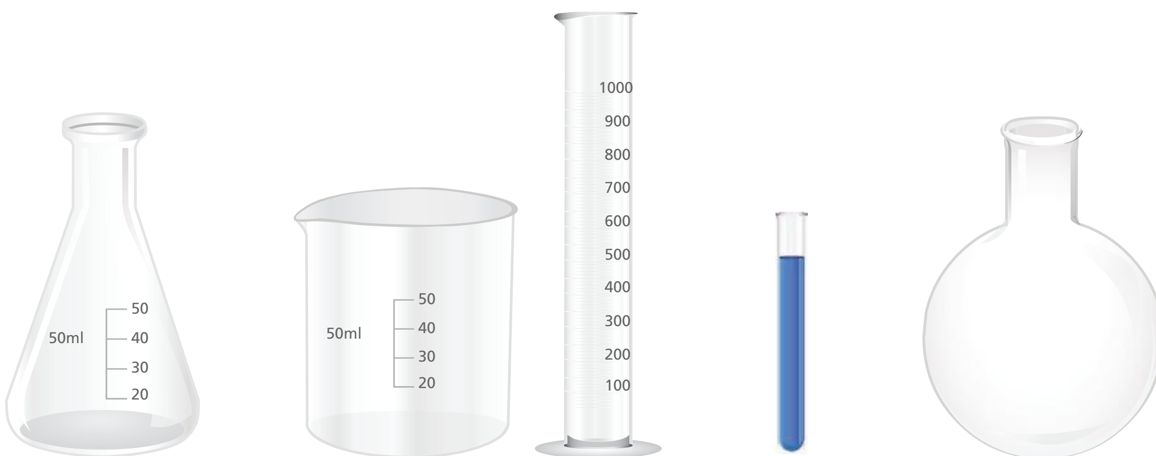


Figure 1.39 Items of laboratory glassware

1 Has it got a pouring spout?

Yes 2

No 3

2 Has it got a broad base?

Yes .... **Beaker**

No .... **Measuring cylinder**

3 Has it got straight sides for the whole of its length?

Yes .... **Boiling tube**

No **4**

4 Has it got sloping sides?

Yes .... **Conical flask**

No .... **Round-bottomed flask**

Figure 1.40 Dichotomous key for identifying laboratory glassware

Questions

Core

1 Why do you think poikilothermic (cold blooded) animals are slowed down by low temperatures? (See Chapter 5.)
2 Which vertebrate classes:
  a are warm-blooded
  b have four legs
  c lay eggs
  d have internal fertilisation
  e have some degree of parental care?
3 Figure 1.32 on page 19 shows some protoctista. Using only the features shown in the drawings, construct a dichotomous key that could be used to identify these organisms.
4 Construct a dichotomous key that would lead an observer to distinguish between the following plants: daffodil, poppy, buttercup, meadow grass, iris (see Figure 1.11, page 10). (There is more than one way.)
  Why this is an 'artificial' key rather than a 'natural' key?

Extended

5 Classify the following organisms: beetle, sparrow, weasel, gorilla, bracken, buttercup.
  For example, butterfly: Kingdom, animal; Group, arthropod; Class, insect.
6 The white deadnettle is *Lamium album*; the red deadnettle is *Lamium purpureum*. Would you expect these two plants to cross-pollinate successfully?
7 If a fire destroys all the above-ground vegetation, the bracken (a type of fern) will still grow well in the next season. Suggest why this should be so.
8 Which kingdoms contain organisms with:
  a many cells
  b nuclei in their cells
  c cell walls
  d hyphae
  e chloroplasts?

Checklist

After studying Chapter 1 you should know and understand the following:

- The seven characteristics of living things are movement, respiration, sensitivity, growth, reproduction, excretion and nutrition.
- A species is a group of organisms that can reproduce to produce fertile offspring.
- The binomial system is an internationally agreed system in which the scientific name of an organism is made up of two parts showing the genus and the species.
- Classification is a way of sorting organisms into a meaningful order, traditionally using morphology and anatomy, but recently also using DNA.
- All living organisms have certain features in common, including the presence of cytoplasm and cell membranes, and DNA as genetic material.
- Animals get their food by eating plants or other animals.
- Arthropods have a hard exoskeleton and jointed legs.
- Crustacea mostly live in water and have more than three pairs of legs.
- Insects mostly live on land and have wings and three pairs of legs.
- Arachnids have four pairs of legs and poisonous mouth parts.
- Myriapods have many pairs of legs.
- Vertebrates have a spinal column and skull.
- Fish have gills, fins and scales.
- Amphibia can breathe in air or in water.
- Reptiles are land animals; they lay eggs with leathery shells.
- Birds have feathers, beaks and wings; they are homoiothermic (warm-blooded).
- Mammals have fur, they suckle their young and the young develop inside the mother.
- Keys are used to identify unfamiliar organisms.
- Dichotomous means two branches, so the user is given a choice of two possibilities at each stage.

- Prokaryotes are microscopic organisms; they have no proper nucleus.
- Protoctists are single-celled organisms containing a nucleus.
- Fungi are made up of thread-like hyphae. They reproduce by spores.
- Plants make their food by photosynthesis.
- Ferns have well-developed stems, leaves and roots. They reproduce by spores.
- Seed-bearing plants reproduce by seeds.
- Flowering plants have flowers; their seeds are in an ovary which forms a fruit.
- Monocots have one cotyledon in the seed; dicots have two cotyledons in the seed.
- Viruses do not possess the features of a living organism.

2 Organisation and maintenance of the organism

Cell structure and organisation
Plant and animal cell structures
Functions of structures

Ribosomes, rough ER and mitochondria
Mitochondria and respiration

Levels of organisation
Specialised cells and their functions
Definitions and examples of tissues, organs and systems

Size of specimens
Calculations of magnification and size, using millimetres

Calculations of magnification using micrometres

Cell structure and organisation

Cell structure

If a very thin slice of a plant stem is cut and studied under a microscope, it can be seen that the stem consists of thousands of tiny, box-like structures. These structures are called **cells**. Figure 2.1 is a thin slice taken from the tip of a plant shoot and photographed through a microscope. Photographs like this are called **photomicrographs**. The one in Figure 2.1 is 60 times larger than life, so a cell which appears to be 2 mm long in the picture is only 0.03 mm long in life.

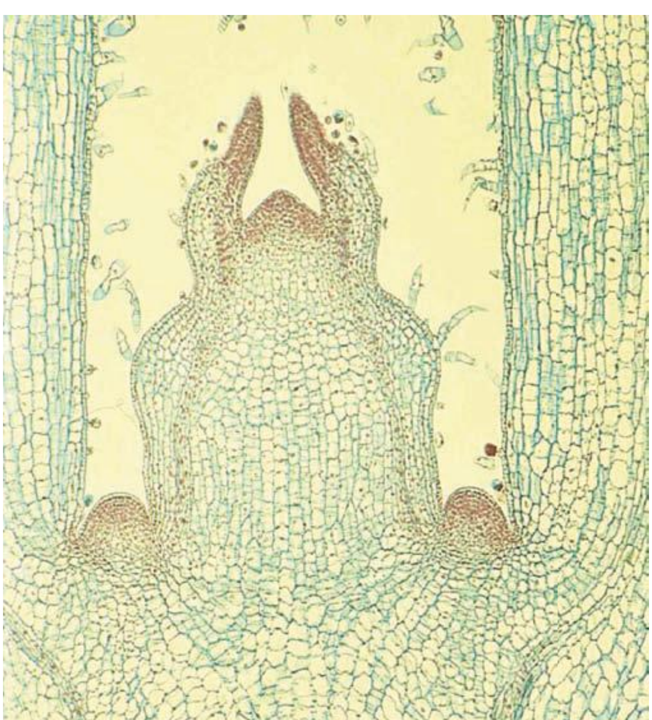


Figure 2.1 Longitudinal section through the tip of a plant shoot (×60). The slice is only one cell thick, so light can pass through it and allow the cells to be seen clearly.

Thin slices of this kind are called **sections**. If you cut *along the length* of the structure, you are taking a **longitudinal section** (Figure 2.2(b)). Figure 2.1 shows a longitudinal section, which passes through two small developing leaves near the tip of the shoot, and two larger leaves below them. The leaves, buds and stem are all made up of cells. If you cut *across* the structure, you make a **transverse section** (Figure 2.2(a)).

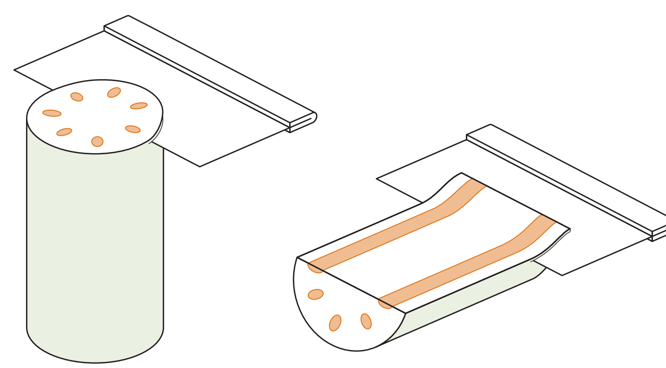


Figure 2.2 Cutting sections of a plant stem

It is fairly easy to cut sections through plant structures just by using a razor blade. To cut sections of animal structures is more difficult because they are mostly soft and flexible. Pieces of skin, muscle or liver, for example, first have to be soaked in melted wax. When the wax goes solid it is then possible to cut thin sections. The wax is dissolved away after making the section.

When sections of animal structures are examined under the microscope, they, too, are seen to be made up of cells but they are much smaller than plant cells and need to be magnified more. The photomicrograph of kidney tissue in Figure 2.3 has been magnified 700 times to show the cells clearly. The sections are often treated with dyes, called **stains**, in order to make the structures inside the cells show up more clearly.

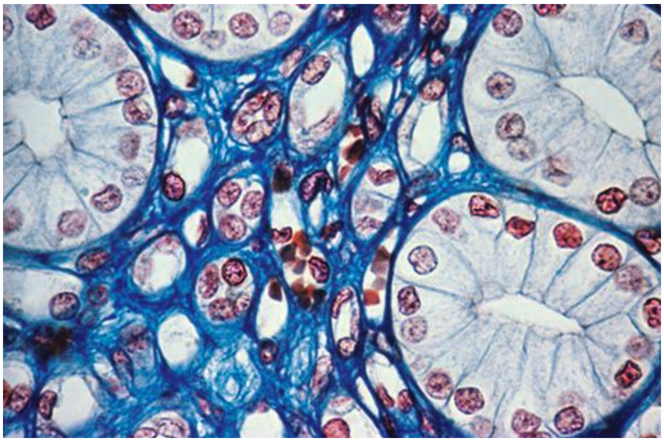


Figure 2.3 Transverse section through a kidney tubule (×700). A section through a tube will look like a ring (see Figure 2.14(b)). In this case, each 'ring' consists of about 12 cells.

Making sections is not the only way to study cells. Thin strips of plant tissue, only one cell thick, can be pulled off stems or leaves (Experiment 1, page 28). Plant or animal tissue can be squashed or smeared on a microscope slide (Experiment 2, page 29) or treated with chemicals to separate the cells before studying them.

There is no such thing as a typical plant or animal cell because cells vary a great deal in their size and shape depending on their function. Nevertheless, it is possible to make a drawing like Figure 2.4 to show features which are present in most cells. *All cells* have a **cell membrane**, which is a thin boundary enclosing the **cytoplasm**. Most cells have a **nucleus**.

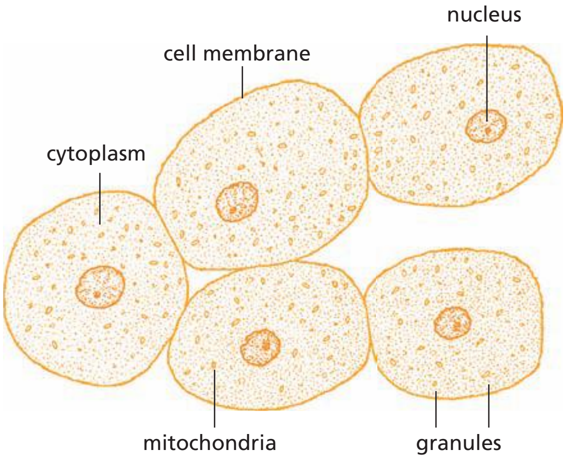


Figure 2.4 A group of liver cells. These cells have all the characteristics of animal cells.

Cytoplasm

Under the ordinary microscope (light microscope), cytoplasm looks like a thick liquid with particles in it. In plant cells it may be seen to be flowing about. The particles may be food reserves such as oil droplets or granules of starch. Other particles are structures known as **organelles**, which have particular functions in the cytoplasm. In the cytoplasm, a great many chemical reactions are taking place which keep the cell alive by providing energy and making substances that the cell needs.

The liquid part of cytoplasm is about 90% water with molecules of salts and sugars dissolved in it. Suspended in this solution there are larger molecules of fats (lipids) and proteins (see Chapter 4). Lipids and proteins may be used to build up the cell structures, such as the membranes. Some of the proteins are **enzymes** (see Chapter 5). Enzymes control the rate and type of chemical reactions which take place in the cells. Some enzymes are attached to the membrane systems of the cell, whereas others float freely in the liquid part of the cytoplasm.

Cell membrane

This is a thin layer of cytoplasm around the outside of the cell. It stops the cell contents from escaping and also controls the substances which are allowed to enter and leave the cell. In general, oxygen, food and water are allowed to enter; waste products are allowed to leave and harmful substances are kept out. In this way the cell membrane maintains the structure and chemical reactions of the cytoplasm.

Nucleus (plural: nuclei)

Most cells contain one nucleus, which is usually seen as a rounded structure enclosed in a membrane and embedded in the cytoplasm. In drawings of cells, the nucleus may be shown darker than the cytoplasm because, in prepared sections, it takes up certain stains more strongly than the cytoplasm. The function of the nucleus is to control the type and quantity of enzymes produced by the cytoplasm. In this way it regulates the chemical changes which take place in the cell. As a result, the nucleus determines what the cell will be, for example, a blood cell, a liver cell, a muscle cell or a nerve cell.

The nucleus also controls cell division, as shown in Figure 2.5. A cell without a nucleus cannot reproduce. Inside the nucleus are thread-like structures called **chromosomes**, which can be seen most easily at the time when the cell is dividing (see Chapter 17 for a fuller account of chromosomes).

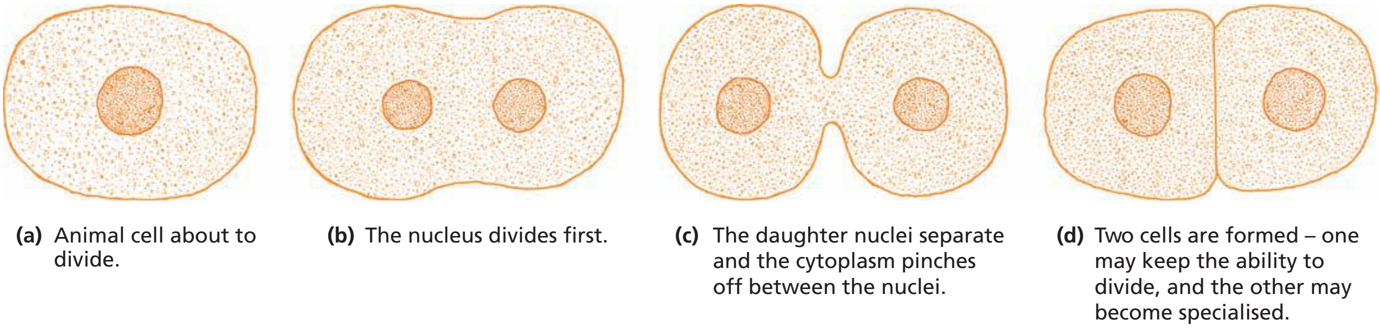


Figure 2.5 Cell division in an animal cell

Plant cells

A few generalised animal cells are represented by Figure 2.4, while Figure 2.6 is a drawing of two palisade cells from a plant leaf. (See 'Leaf structure' in Chapter 6.)

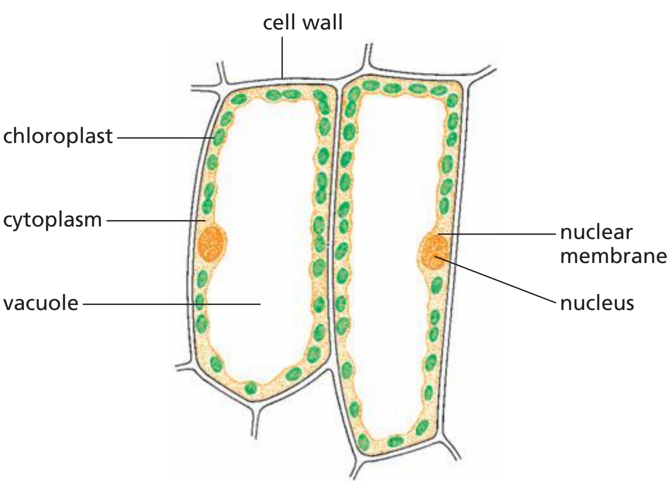


Figure 2.6 Palisade cells from a leaf

Plant cells differ from animal cells in several ways.

1 Outside the cell membrane they all have a **cell wall** which contains cellulose and other compounds. It is non-living and allows water and dissolved substances to pass through. The cell wall is not selective like the cell membrane. (Note that plant cells *do* have a cell membrane but it is not easy to see or draw because it is pressed against the inside of the cell wall (see Figure 2.7).)

Under the microscope, plant cells are quite distinct and easy to see because of their cell walls. In Figure 2.1 it is only the cell walls (and in some cases the nuclei) which can be seen. Each plant cell has its own cell wall but the boundary between two cells side by side does not usually show up clearly. Cells next to each other therefore appear to be sharing the same cell wall.

2 Most mature plant cells have a large, fluid-filled space called a **vacuole**. The vacuole contains **cell sap**, a watery solution of sugars, salts and sometimes pigments. This large, central vacuole pushes the cytoplasm aside so that it forms just a thin lining inside the cell wall. It is the outward pressure of the vacuole on the cytoplasm and cell wall which makes plant cells and their tissues firm (see 'Osmosis' in Chapter 3). Animal cells may sometimes have small vacuoles in their cytoplasm but they are usually produced to do a particular job and are not permanent.

3 In the cytoplasm of plant cells are many organelles called **plastids**. These are not present in animal cells. If they contain the green substance **chlorophyll**, the organelles are called **chloroplasts** (see Chapter 6). Colourless plastids usually contain starch, which is used as a food store. (Note: the term *plastid* is **not** a syllabus requirement.)

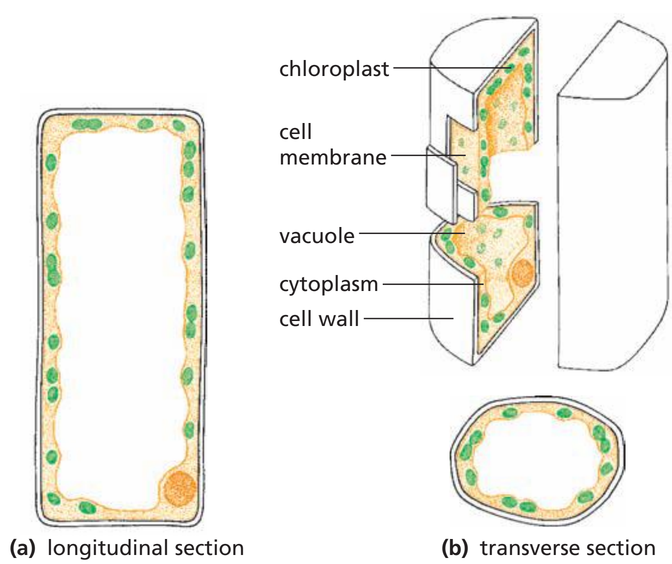


Figure 2.7 Structure of a palisade mesophyll cell. It is important to remember that, although cells look flat in sections or in thin strips of tissue, they are in fact three-dimensional and may seem to have different shapes according to the direction in which the section is cut. If the cell is cut across it will look like (b); if cut longitudinally it will look like (a).

The shape of a cell when seen in a transverse section may be quite different from when the same cell is seen in a longitudinal section and Figure 2.7 shows why this is so. Figures 8.4(b) and 8.4(c) on page 112 show the appearance of cells in a stem vein as seen in transverse and longitudinal section.

Table 2.1 Summary: the parts of a cell

	Name of part	Description	Where found	Function (supplement only)
Animal and plant cells	cytoplasm	jelly-like, with particles and organelles in	enclosed by the cell membrane	contains the cell organelles, e.g. mitochondria, nucleus site of chemical reactions
	cell membrane	a partially permeable layer that forms a boundary around the cytoplasm	around the cytoplasm	prevents cell contents from escaping controls what substances enter and leave the cell
	nucleus	a circular or oval structure containing DNA in the form of chromosomes	inside the cytoplasm	controls cell division controls cell development controls cell activities
Plant cells only	cell wall	a tough, non-living layer made of cellulose surrounding the cell membrane	around the outside of plant cells	prevents plant cells from bursting allows water and salts to pass through (freely permeable)
	vacuole	a fluid-filled space surrounded by a membrane	inside the cytoplasm of plant cells	contains salts and sugars helps to keep plant cells firm
	chloroplast	an organelle containing chlorophyll	inside the cytoplasm of some plant cells	traps light energy for photosynthesis

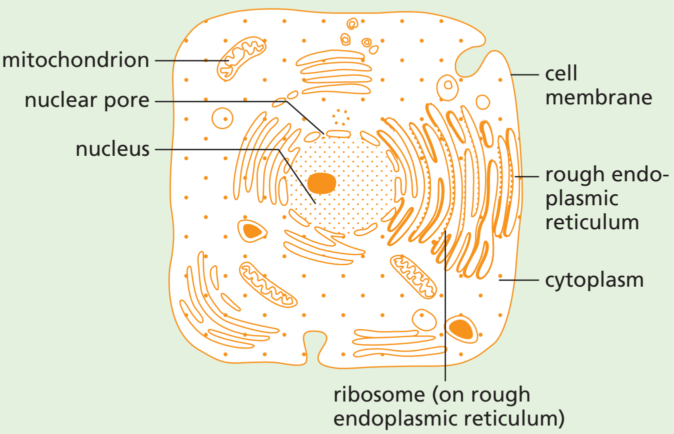
When studied at much higher magnifications with the **electron microscope**, the cytoplasm of animal and plant cells no longer looks like a structureless jelly but appears to be organised into a complex system of membranes and vacuoles. Organelles present include the **rough endoplasmic reticulum**, a network of flattened cavities surrounded by a membrane, which links with the nuclear membrane. The membrane holds **ribosomes**, giving its surface a rough appearance. Rough endoplasmic reticulum has the function of producing, transporting and storing proteins. Ribosomes can also be found free in the cytoplasm. They build up the cell's proteins (see Chapter 4).

Mitochondria are tiny organelles, which may appear slipper-shaped, circular or oval when viewed in section. In three dimensions, they may be spherical, rod-like or elongated. They have an outer membrane and an inner membrane with many inward-pointing folds. Mitochondria are most numerous in regions of rapid chemical activity and are responsible for producing energy from food substances through the process of aerobic respiration (see Chapter 12).

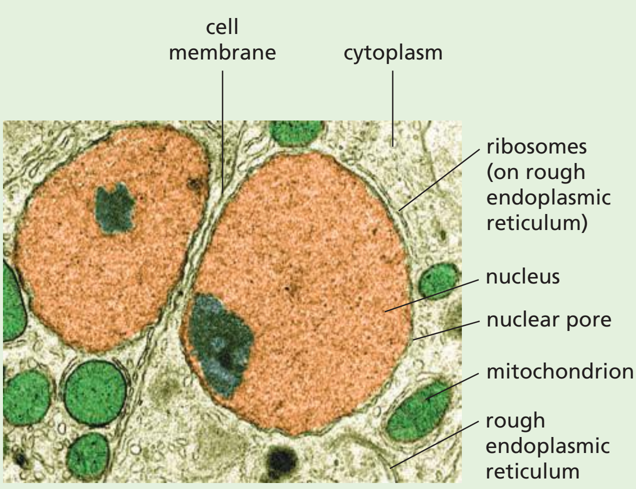
Note that prokaryotes do not possess mitochondria or rough endoplasmic reticulum in their cytoplasm.

Figure 2.8(a) is a diagram of an animal cell magnified 10 000 times. Figure 2.8(b) is an electron micrograph of a liver cell. Organelles in the cytoplasm can be seen clearly. They have recognisable shapes and features.

Figure 2.8(c) is an electron micrograph of a plant cell. In addition to the organelles already named and described, other organelles are also present such as chloroplasts and a cell wall.

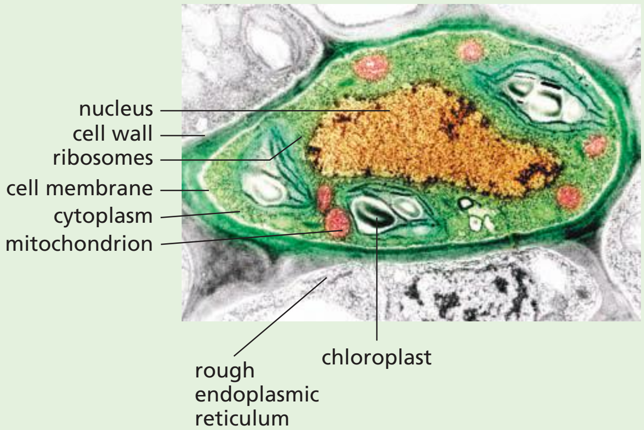


(a) diagram of a liver cell (×10 000)



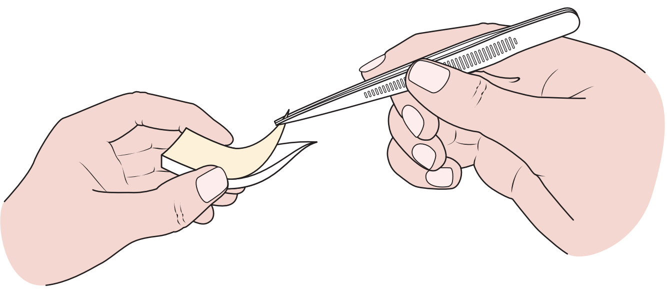
(b) electron micrograph of two liver cells (×10 000)

Figure 2.8 Cells at high magnification

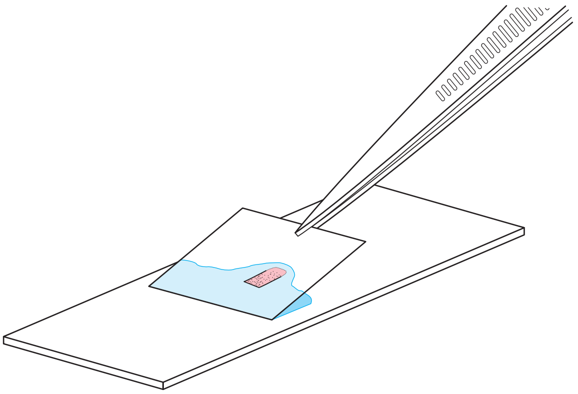


(c) electron micrograph of a plant cell (×6000)

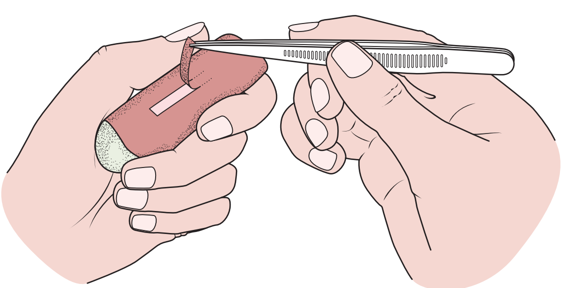
Figure 2.8 Cells at high magnification (continued)



(a) peel the epidermis from the inside of an onion bulb leaf



(b) place the epidermis on to the slide, adding 2–3 drops of iodine solution and carefully lowering a coverslip on to it



(c) alternatively, peel a strip of red epidermis from a piece of rhubarb skin

Figure 2.9 Looking at plant cells

Practical work

Looking at cells

1 Plant cells – preparing a slide of onion epidermis cells

The onion provides a very useful source of epidermal plant tissue which is one cell thick, making it relatively easy to set up as a temporary slide. The onion is made up of fleshy leaves. On the incurve of each leaf there is an epidermal layer which can be peeled off (Figure 2.9(a)).

- Using forceps, peel a piece of epidermal tissue from the incurve of an onion bulb leaf.
- Place the epidermal tissue on a glass microscope slide.
- Using a scalpel, cut out a 1 cm square of tissue (discarding the rest) and arrange it in the centre of the slide.
- Add two to three drops of iodine solution. (This will stain any starch in the cells and provides a contrast between different components of the cells.)
- Using forceps, a mounted needle or a wooden splint, support a coverslip with one edge resting near to the onion tissue, at an angle of about 45° (Figure 2.9(b)).
- Gently lower the coverslip over the onion tissue, trying to avoid trapping any air bubbles. (Air bubbles will reflect light when viewing under the light microscope, obscuring the features you are trying to observe.)
- Leave the slide for about 5 minutes to allow the iodine stain to react with the specimen. The iodine will stain the cell nuclei pale yellow and the starch grains blue.
- Place the slide on to the microscope stage, select the lowest power objective lens and focus on the specimen. Increase the magnification using the other objective lenses. Under high power, the cells should look similar to those shown in Figure 2.10.
- Make a large drawing of **one** cell and label the following parts: cell wall, cell membrane, cytoplasm, nucleus.

An alternative tissue is rhubarb epidermis (Figure 2.9(c)). This can be stripped off from the surface of a stalk and treated in the same way as the onion tissue. If red epidermis from rhubarb stalk is used, you will see the red cell sap in the vacuoles.

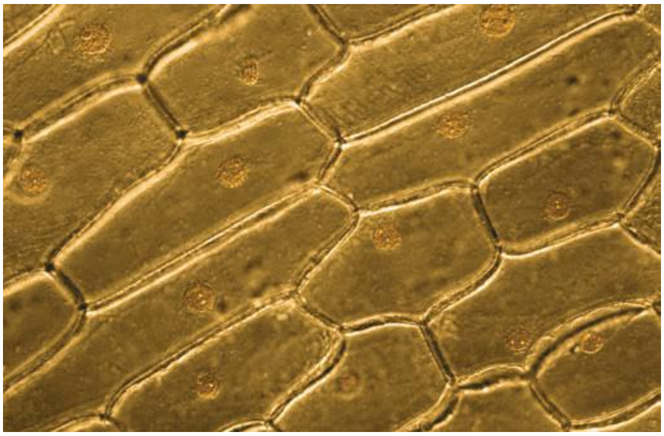


Figure 2.10 Onion epidermis cells

2 Plant cells – preparing cells with chloroplasts

- Using forceps, remove a leaf from a moss plant.
- Place the leaf in the centre of a microscope slide and add one or two drops of water.
- Place a coverslip over the leaf.
- Examine the leaf cells with the high power objective of a microscope. The cells should look similar to those shown in Figure 2.11.

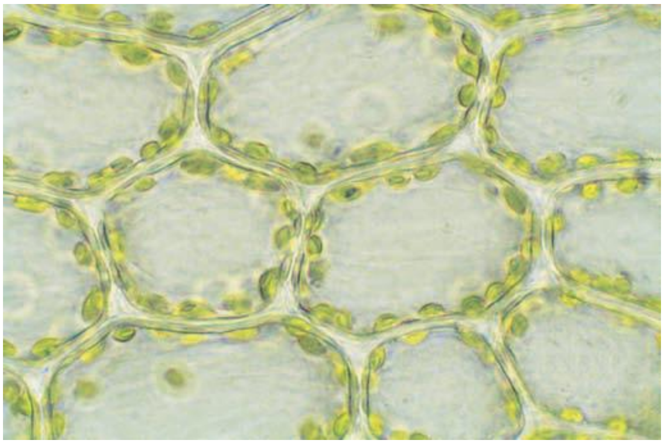


Figure 2.11 Cells in a moss leaf (×500). The vacuole occupies most of the space in each cell. The chloroplasts are confined to the layer of cytoplasm lining the cell wall.

3 Animal cells – preparing human cheek cells

Human cheek cells are constantly being rubbed off inside the mouth as they come in contact with the tongue and food. They can therefore be collected easily for use in a temporary slide.

Note: The Department of Education and Science and, subsequently, Local Authorities, used to recommend that schools should not use the technique which involves studying the epithelial cells which appear in a smear taken from the inside of the cheek. This was because of the very small risk of transmitting the AIDS virus. However, this guidance has now changed. A document, *Safety in Science Education* (1996) by the DfEE in Britain states that official government guidance on cheek cells has been effectively reversed, indicating that the use of cotton buds is now 'permitted' together with appropriate precautions to treat contaminated items with disinfectant or by autoclaving.

- Rinse your mouth with water to remove any fragments of food.
- Take a cotton bud from a freshly opened pack. Rub the cotton bud lightly on the inside of your cheek and gums to collect some cheek cells in saliva.
- Rub the cotton bud on to the centre of a clean microscope slide, to leave a sample of saliva. Repeat if the sample is too small. Then drop the cotton bud into a container of absolute alcohol or disinfectant.
- Add two to three drops of methylene blue dye. (This will stain parts of the cheek cells to make nuclei more visible.)
- Using forceps, a mounted needle or wooden splint, support a coverslip with one edge resting near to the cheek cell sample, at an angle of about 45°. Gently lower the coverslip over the tissue, trying to avoid trapping any air bubbles. (Air bubbles will reflect light when viewing under the light microscope, obscuring the features you are trying to observe.)
- Leave the slide for a few minutes to allow the methylene blue stain to react with the specimen.
- Place the slide on to the microscope stage, select the lowest power objective lens and focus on the specimen. Increase the magnification using the other objective lenses. Under high power, the cells should look similar to those shown in Figure 2.12, but less magnified.
- Make a large drawing of **one** cell and label the following parts: cell membrane, cytoplasm, nucleus.
- Place your used slide in laboratory disinfectant before washing.

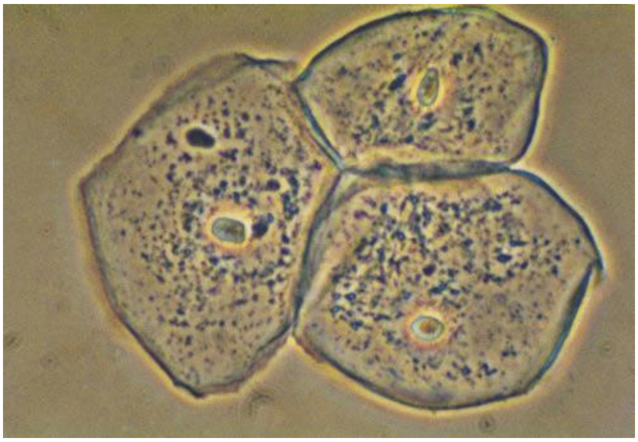


Figure 2.12 Cells from the lining epithelium of the cheek (×1500)

An alternative method of obtaining cells is to press some transparent sticky tape on to a well-washed wrist. When the tape is removed and studied under the microscope, cells with nuclei can be seen. A few drops of methylene blue solution will stain the cells and make the nuclei more distinct.

Levels of organisation

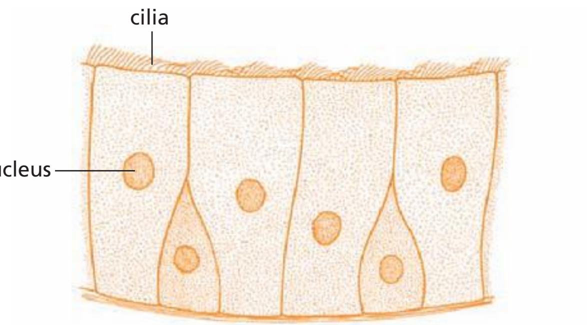
Specialisation of cells

Most cells, when they have finished dividing and growing, become specialised. When cells are specialised:

- they do one particular job
- they develop a distinct shape
- special kinds of chemical change take place in their cytoplasm.

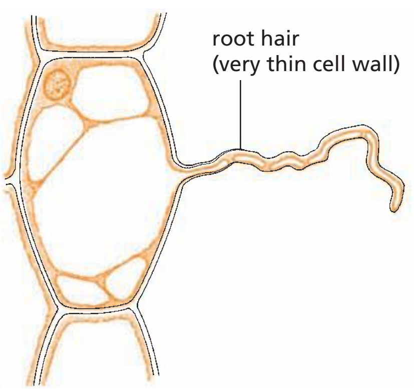
The changes in shape and the chemical reactions enable the cell to carry out its special function. Red blood cells and root hair cells are just two examples of specialised cells. Figure 2.13 shows a variety of specialised cells.

The specialisation of cells to carry out particular functions in an organism is sometimes referred to as '**division of labour**' within the organism. Similarly, the special functions of mitochondria, ribosomes and other cell organelles may be termed division of labour within the cell.



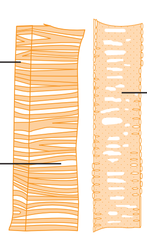
(a) ciliated cells

These cells form the lining of the nose and windpipe, and the tiny cytoplasmic 'hairs', called cilia, are in a continual flicking movement which creates a stream of fluid (mucus) that carries dust and bacteria through the bronchi and trachea, away from the lungs.



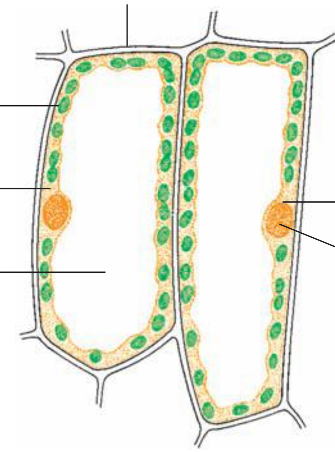
(b) root hair cell

These cells absorb water and mineral salts from the soil. The hair-like projection on each cell penetrates between the soil particles and offers a large absorbing surface. The cell membrane is able to control which dissolved substances enter the cell.



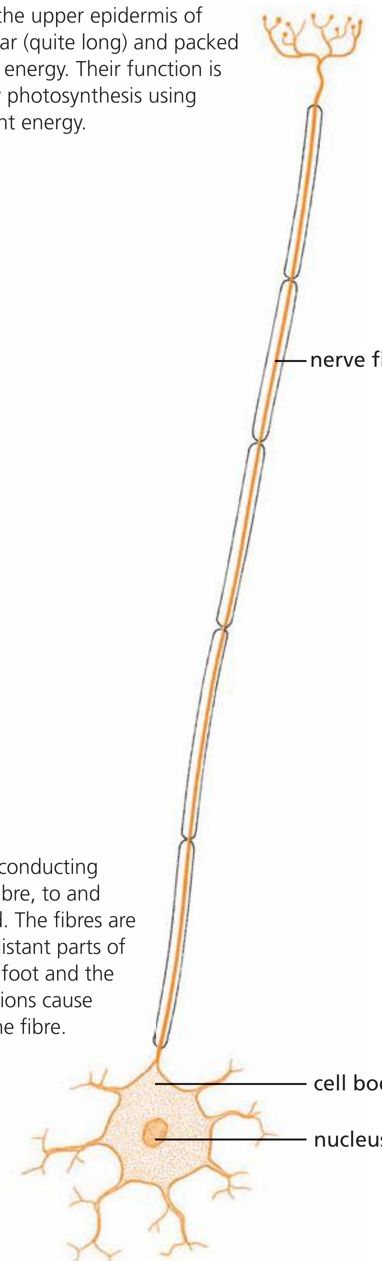
(c) xylem vessels

These cells transport mineral ions from the roots to the leaves. A substance called lignin impregnates and thickens the cell walls making the cells very strong and impermeable. This gives the stem strength. The lignin forms distinctive patterns in the vessels – spirals, ladder shapes, reticulate (net-like) and pitted. Xylem vessels are made up of a series of long xylem cells joined end-to-end (Figure 8.4(a)). Once a region of the plant has stopped growing, the end walls of the cells are digested away to form a continuous, fine tube (Figure 8.4(c)). The lignin thickening prevents the free passage of water and nutrients, so the cytoplasm in the cells dies. Effectively, the cells form long, thin, strong straws.



(d) palisade mesophyll cells

These are found underneath the upper epidermis of plant leaves. They are columnar (quite long) and packed with chloroplasts to trap light energy. Their function is to make food for the plant by photosynthesis using carbon dioxide, water and light energy.



(e) nerve cells

These cells are specialised for conducting electrical impulses along the fibre, to and from the brain and spinal cord. The fibres are often very long and connect distant parts of the body to the CNS, e.g. the foot and the spinal column. Chemical reactions cause the impulses to travel along the fibre.

Figure 2.13 Specialised cells (not to scale)