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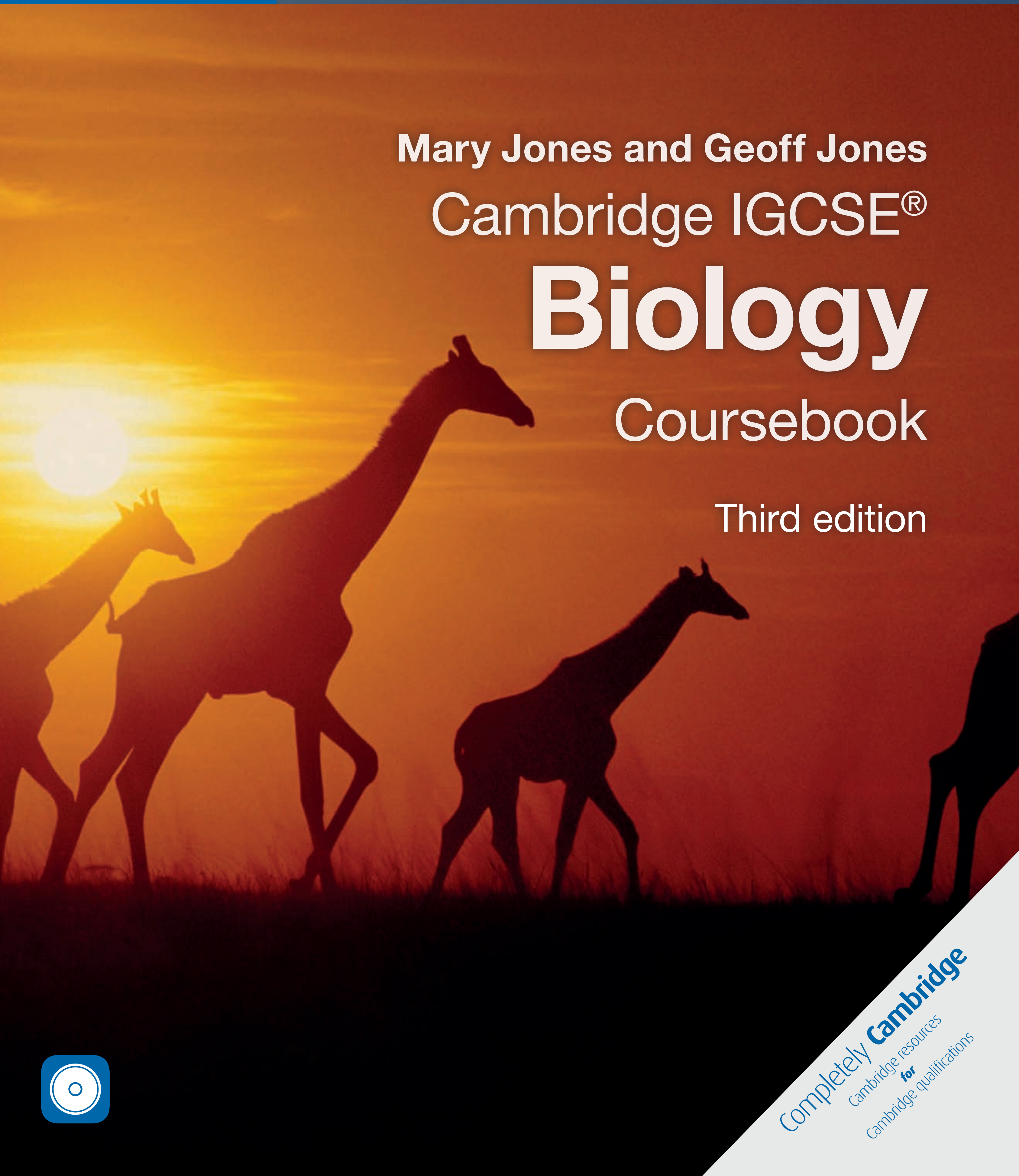
Mary Jones and Geoff Jones

Cambridge IGCSE® Biology Coursebook

Third edition



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Contents

Introduction

This book has been written to help you to do well in your Cambridge International Examinations IGCSE Biology examination (0610). We hope that you enjoy using it.

The book can also be used with the Cambridge 'O' level Biology syllabus (5090).

Core and Supplement

Your teacher will tell you whether you are studying just the Core part of the Biology syllabus, or whether you are studying the Supplement as well. If you study the Core only, you will be entered for Papers 1 and 3 and either Paper 5 or 6, and can get a maximum of Grade C. If you also study the Supplement, you may be entered for Papers 2 and 4, and either Paper 5 or 6, and will be able to get a maximum of Grade A*. The Supplement material in this book is marked by a letter 'S' and brown bars in the margin, like this.

Definitions

There are quite a lot of definitions in the IGCSE syllabus that you need to learn by heart. These are all in this book, at appropriate points in each chapter, inside boxes with a heading 'Key definition'. Make sure you learn these carefully.

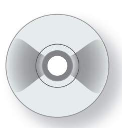
Questions

Each chapter has several sets of Questions within it. Most of these require quite short answers, and simply test if you have understood what you have just read (or what you have just been taught).

At the end of each chapter, there are some longer questions testing a range of material from the chapter. Some of these are past questions from Cambridge exam papers, or are in a similar style to Cambridge questions.

Activities

Each chapter contains Activities. These will help you to develop the practical skills that will be tested in your IGCSE Biology examination. There are more Activities on the CD-ROM. These are marked with this symbol:



There are two possible exams to test your practical skills, called Paper 5 and Paper 6. Your teacher will tell you which of these you will be entered for. They are equally difficult, and you can get up to Grade A* on either of them. You should try to do the Activities no matter which of these papers you are entered for.

Summary

At the end of each chapter, there is a short list of the main points covered in the chapter. Remember, though, that these are only very short summaries, and you'll need to know more detail than this to do really well in the exam.

The CD-ROM

There is a CD-ROM in the back of the book. You'll also find the Summaries on the CD-ROM. You can use the revision checklists on the CD-ROM to check off how far you have got with learning and understanding each idea.

The CD-ROM also contains a set of interactive multiple-choice questions testing whether you know and understand the material from each chapter.

You'll find some self-assessment checklists on the CD-ROM too, which you can print off and use to assess yourself each time you observe and draw a specimen, construct a results chart, draw a graph from a set of results or plan an experiment. These are all very important skills, and by using these checklists you should be able to improve your performance until you can do them almost perfectly every time.

There are some suggestions on the CD-ROM about how you can give yourself the very best chance of doing well in your exams, by studying and revising carefully. There are also some practice exam papers.

Workbook

There is a workbook to go with this textbook. If you have one, you will find it really helpful in developing your skills, such as handling information and solving problems, as well as some of the practical skills.

Acknowledgements

Cover xxxx p. 1 Alamy; 2 Geoff Jones; pp. 7*t*, 7*b* Alamy; p. 11 Ian Esland xx; p.15 Geoff Jones; p. 17 Geoff Jones; p. 18 Kenneth Ingram; pp. 20*t*, 20*b* Eleanor Jones; p. 21 Biophoto Associates/SPL; p.22*t*, 22*b*,22*br* SPL; p. 26 SPL; p. 28 Alamy; p. 34 Geoff Jones; p. 40 SPL; p. 42 SPL; p. 43 SPL; p. 44 Alamy; p.45 SPL; 46*t*, 46*b* SPL; p. 49 Alamy; p. 58 SPL; p. 61*t* Biophoto Associates/SPL; p.61*b* SPL; p. 61*r* Andrew Syred/SPL; p. 65 Nigel Cattlin/Alamy; p. 67 Alamy; p. 73 SPL; p. 75 7.3-7.6 Geoff Jones; p. 77*l* Alex Segre/Alamy; p. 77*r* Images of Africa Photobank/Alamy; p. 87 Biophoto Associates/SPL; p. 88*l* SPL; p.88*r* SPL; p. 93 Alamy; p. 94 Andrew Syred/SPL; p. 95 J.C. Revy/SPL; p.96*t* SPL; p. 96*b* SPL; p. 106 Alamy; p. 110 Alamy; p. 112 Alamy; p. 114 Janine Photolibrary/Alamy; p. 115 Prof. P. Motta/Dept. of Anatomy/University "La Sapienza", Rome/SPL; pp. 118, 120, 121 Phototake Inc./Alamy; p. 127 Alamy;p. 129*t* Alamy; p. 129*b* Alamy; p. 130 Alamy; p. 131 Alamy; p. 132*l* Alamy; p. 132*r* Alamy; p. 136 Alamy; p. 137 Alamy; p. 140 Alamy; p. 150 Rick Rickman/NewSport/Corbis; p. 153 Alamy; p. 161 SPL; p. 164 Wendy Lee; p. 165 Visual Ideas/Nora/Corbis; p. 175 SPL; p. 178 Alamy; p.185*l* SPL; p. 186*r* SPL; p. 188 Alamy; p. 189*t* CNRI/SPL; p.189*b* Alamy; p. 191*l* Zuma Press/Zuma/Corbis; 191*r* St Bartholomew's Hospital/SPL; p. 192 XXXX; pp 194*l*, 194*r* Biophoto Associates/SPL; p. 195 SPL; p. 197 Alamy; p. 201 Geoff Jones; p. 202*t* Alamy: p. 202*b* Pictox/Alamy; p. 204 SPL; p. 208 Alamy; p. 212*t* SPL; p. 212*b* SPL; p. 215 Alamy; p. 219 Alamy; p. 225 SPL; p. 230 Alamy; p. 231*l* Chery Power/SPL; 231*r* CNRI/SPL; p. 232 Leonard Lessin/FBPA/SPL;p. 239 Alamy; p. 247*l* Alamy; p. 247*r* Alamy; p. 248 *tr* Wendy Lee; p. 248*t* Imagebroker/Alamy; p. 248*b* Sam Sangster/Alamy; p. 251*l* Alamy; p 251*tr* Alamy; p. 251*br* Geoff Jones; p. 253*l* Jayanta Dey/epa/Corbis; p 253*r* Mary Evans Picture Library/Alamy; p.254 Pat & Tom Leeson/SPL; p. 255 Stephen Dalton/NHPA; p. 257 Agence Nature/NHPA; p. 259*tb* Geoff Jones; p. 259*br* Terry Matthews/Alamy; p. 262 Alamy; p. 264 SPL; p. 278 SPL; p. 280 SPL; p. 281 SPL; p. 282*l* SPL; p. 282*r* SPL; p. 283 SPL; p. 287 SPL; p. 292 Alamy; p. 293*bl* David South/Alamy; 293*tr* David R. Frazier Photolibrary, Inc/Alamy; p. 294*tl* SPL; p. 294*tr* Alamy; p. 294*bl* SPL; p. 295*t* Alamy; p295*b* Alamy; p. 296*l* Gideon Mendel for Action Aid/Corbis; p. 296*r* Alamy; p. 297*tl* Alamy; 297*bl* Sylvia Cordaiy Photo Library Ltd/Alamy; p. 297*tr* Geoff Jones; p.297*br* Geoff Jones; p. 301*l* Lou Linwei/Alamy; p. 301*r* Jim West/Alamy; p. 303 Blickwinkel/Alamy; p. 305 Nigel Cattlin/Alamy; p. 306 Alamy; p. 308 Alamy; p. 312 Alamy; p. 313 Alamy; p.314*l* Alamy; p. 314*tr* Alamy; p. 314*br* Alamy; p. 315 Alamy

Abbreviations
SPL = Science Photo Library
t = top, *b* = bottom, *l* = left, *r* = right

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1 Classification

In this chapter, you will find out about:

- the characteristics of living things
- naming organisms using the binomial system
- how living organisms are classified
- how to use dichotomous keys to identify organisms.

The puzzle of the platypus

In 1788, British settlers arrived in Australia. They were amazed by many of the animals that they saw, and a strange animal with fur, webbed feet and a beak was among the most puzzling (Figure **1.1**).

People had already been living in Australia for almost 50 000 years, and different groups of these indigenous people had various names for this animal, such as dulawarrung. But the British arrivals were not satisfied with just giving the animal a name. They wanted to classify it – to decide which group of animals it belonged in.

And this was where the problem began. The animal had a beak and webbed feet, like a duck. It had fur, like a mole. No-one knew whether it laid eggs or gave birth to live young. So was it a bird? Was it a mammal? No-one could decide.

In 1799, a dead specimen of this strange animal was taken to England, where it was studied by Dr George Shaw. To begin with, he thought it was a hoax. He looked very carefully to see if someone had stitched the beak onto the head, but no – it was clearly a genuine part of the animal.

Dr Shaw gave the animal a Latin name, *Platypus anatinus*. 'Platypus' means 'flat-footed' and 'anatinus' means 'like a duck'. However, someone then pointed out that the name *Platypus* had already been taken, and belonged to a species of beetle. So another name was suggested by a German scientist, who gave it the name *Ornithorhynchus paradoxus*. The first word means 'nose like a bird' and the second means 'puzzling'. This is the Latin name that is used for the animal today.

Although the Latin name *Platypus* could not be used, people still called the animal a platypus. In the following years, proof was found that platypuses lay eggs, rather than giving birth to live young. However, they feed their young on milk, which is a characteristic feature of mammals. Scientists eventually decided to classify the platypus as a mammal, despite its odd beak and the fact that it lays eggs. It was put into a new group of mammals, called monotremes, which also includes the echidnas (spiny anteaters).

Figure 1.1 The platypus is superbly adapted for hunting prey in water.

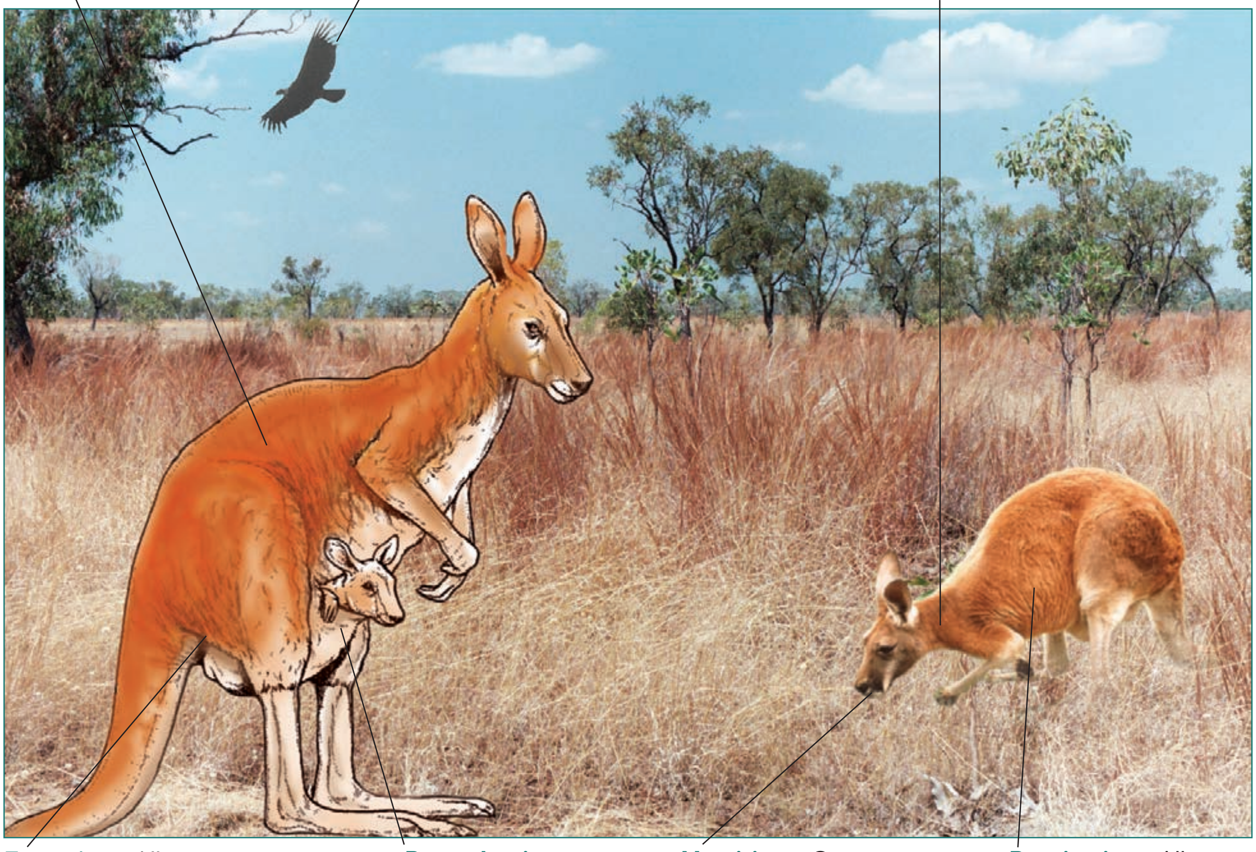
1.1 Characteristics of living things

Biology is the study of living things, which are often called **organisms**. Living organisms have seven features or characteristics which make them different from objects that are not alive (Figure **1.2**). The definitions of these characteristics are shown in the boxes below and on the opposite page. You should learn these definitions now, but you will find out much more about each of them later in this book.

Growth All organisms begin small and get larger, by the growth of their cells and by adding new cells to their bodies.

Movement All organisms are able to move to some extent. Most animals can move their whole body from place to place, and plants can slowly move parts of themselves.

Sensitivity All organisms pick up information about changes in their environment, and react to the changes.



Excretion All organisms produce unwanted or toxic waste products as a result of their metabolic reactions, and these must be removed from the body.

Reproduction Organisms are able to make new organisms of the same species as themselves.

Nutrition Organisms take substances from their environment and use them to provide energy or materials to make new cells.

Respiration All organisms break down glucose and other substances inside their cells, to release energy that they can use.

Figure 1.2 Characteristics of living organisms.

Key definitions

movement – an action by an organism causing a change of position or place

respiration – the chemical reactions in cells that break down nutrient molecules and release energy

sensitivity – the ability to detect and respond to changes in the environment

growth – a permanent increase in size

reproduction – the processes that make more of the same kind of organism

excretion – removal from organisms of toxic materials and substances in excess of requirements

nutrition – taking in of materials for energy, growth and development

Key definitions

movement – an action by an organism or part of an organism causing a change of position or place

respiration – the chemical reactions in cells that break down nutrient molecules and release energy for metabolism

sensitivity – the ability to detect or sense stimuli in the internal or external environment and to make appropriate responses

growth – a permanent increase in size and dry mass by an increase in cell number or cell size or both

excretion – removal from organisms of the waste products of metabolism (chemical reactions in cells including respiration), toxic materials and substances in excess of requirements

nutrition – 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

In addition to these seven characteristics, living organisms have another feature in common. When we study living organisms under a microscope, we can see that they are all made of cells. These cells all have:

- cytoplasm
- a cell membrane
- a chemical called DNA, making up their genetic material
- ribosomes, which are used for making proteins inside the cell
- enzymes that are used to help the cell to carry out anaerobic respiration.

You can find out more about the structure of cells in Chapter **2**.

1.2 Classification

Classification means putting things into groups. There are many possible ways in which we could group living organisms. For example, we could put all the organisms with legs into one group, and all those without legs into another. Or we could put all red organisms into one group, and all blue ones into another. The first of these ideas would be much more useful to biologists than the second.

The main reason for classifying living things is to make it easier to study them. For example, we put humans, dogs, horses and mice into one group (the mammals) because they share certain features (for example, having hair) that are not found in other groups. We think that all mammals share these features because they have all descended from the same ancestor that lived long ago. The ancestor that they all share is called a **common ancestor**. The common ancestor that gave rise to all the mammals lived more than 200 million years ago.

We would therefore expect all mammals to have bodies that have similar structures and that work in similar ways. If we find a new animal that has hair and suckles its young on milk, then we know that it belongs in the mammal group. We will already know a lot about it, even before we have studied it at all.

Using DNA to help with classification

In the past, the only ways that biologists could decide which organisms were most closely related to each other was to study the structure of their bodies. They looked carefully at their **morphology** (the overall form and shape of their bodies, such as whether they had legs or wings) and their **anatomy** (the detailed body structure, which could be determined by dissection). We still use these methods of classification today. But we now have new tools to help to work out evolutionary relationships, and one of the most powerful of these is the study of **DNA**.

DNA is the chemical from which our chromosomes are made. It is the genetic material, passed on from one generation to the next. You can read more about its structure in Chapter **4**, where you will find out that each DNA molecule is made up of strings of smaller molecules, containing four different **bases**. These bases, called A, C, G and T, can be arranged in any order. Biologists can compare the sequences of bases in the

S DNA of organisms from two different species. The more similar the base sequences, the more closely related the species are to one another. They have a more recent common ancestor than species that have DNA base sequences that are less similar.

The classification system

The first person to try to classify organisms in a scientific way was a Swedish naturalist called Linnaeus. He introduced his system of classification in 1735. He divided all the different kinds of living things into groups called **species**. He recognised 12 000 different species. Linnaeus's species were groups of organisms that shared the same appearance and behaviour. We still use this system today. Biologists do not always agree on exactly how to define a species, but usually we say that organisms belong to the same species if they can breed together successfully, and the offspring that they produce can also breed.

Species are grouped into larger groups called genera (singular: **genus**). Each genus contains several species with similar characteristics (Figure **1.3**). Several genera are then grouped into a family, families into orders, orders into classes, classes into phyla and finally phyla into **kingdoms**. Some of the more important groups are described in this chapter.

Figure **1.3** shows five animals that all belong to the mammal order. You can see that they all have hair, which is a characteristic feature of mammals. The animals have been classified into two groups – horse-like mammals and dog-like mammals. (What features do you think differ between these two groups?) The horse-like mammals all belong to the genus *Equus*. The dog-like ones belong to the genus *Canis*.

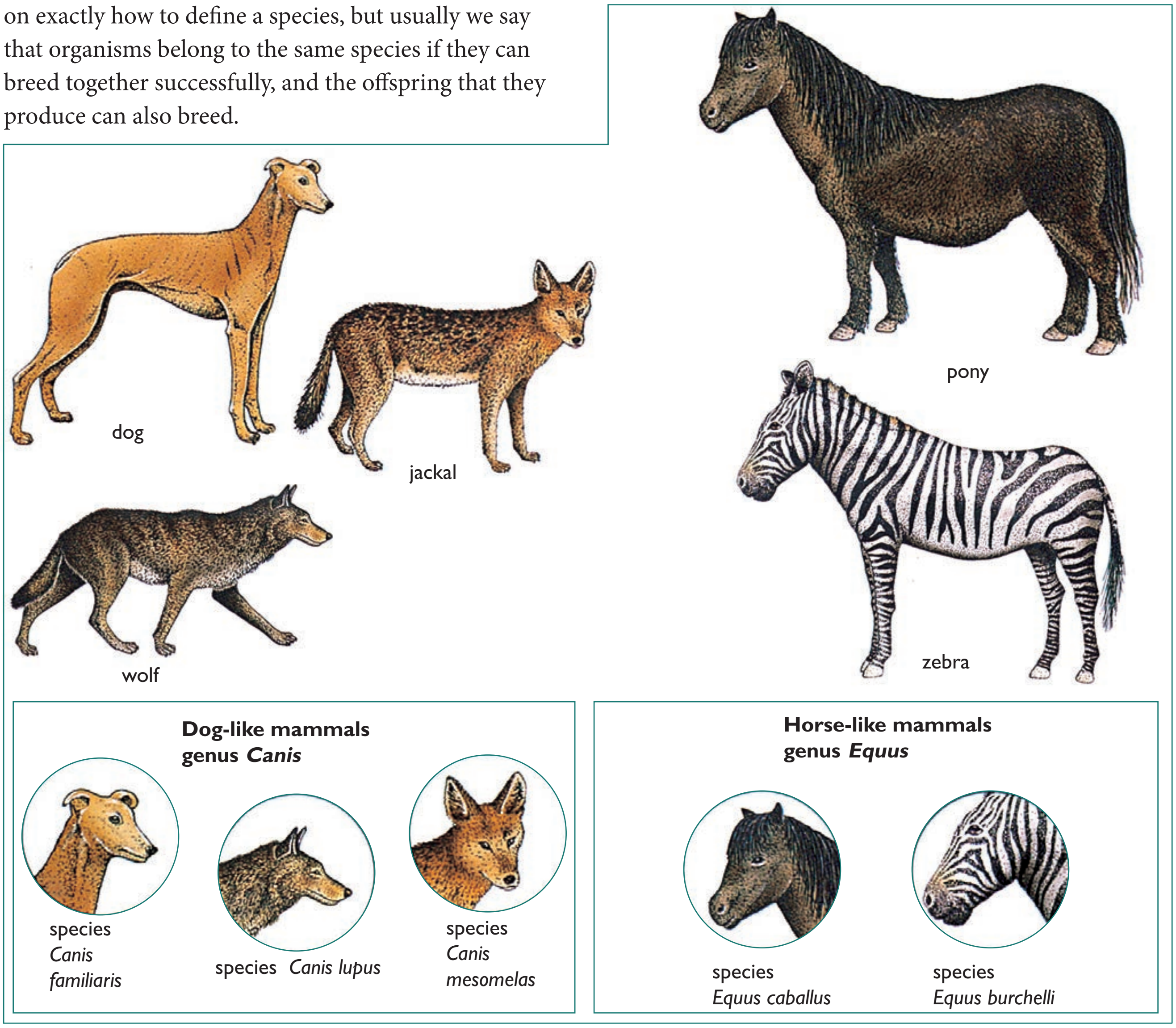


Figure 1.3 The binomial naming system.

The binomial naming system

Linnaeus gave every species of living organism two names, written in Latin. This is called the **binomial system**. The first name is the name of the genus the organism belongs to, and always has a capital letter. The second name is the name of its species, and always has a small letter. This two-word name is called a **binomial**.

For example, a wolf belongs to the genus *Canis* and the species *lupus*. Its binomial is *Canis lupus*. These names are printed in italics. When you write a Latin name, you cannot write in italics, so you should underline it instead. The genus name can be abbreviated like this: *C. lupus*.

Key definition

species – a group of organisms that can reproduce and produce fertile offspring

binomial system – an internationally ageeed system in which the scientific name of an organism is made up of two parts showing the genus and species

Study tip

Do take care to write Latin names (binomials) correctly. You will often see them written wrongly in the media! You should always use a capital letter for the first name and a small letter for the second name.

Question

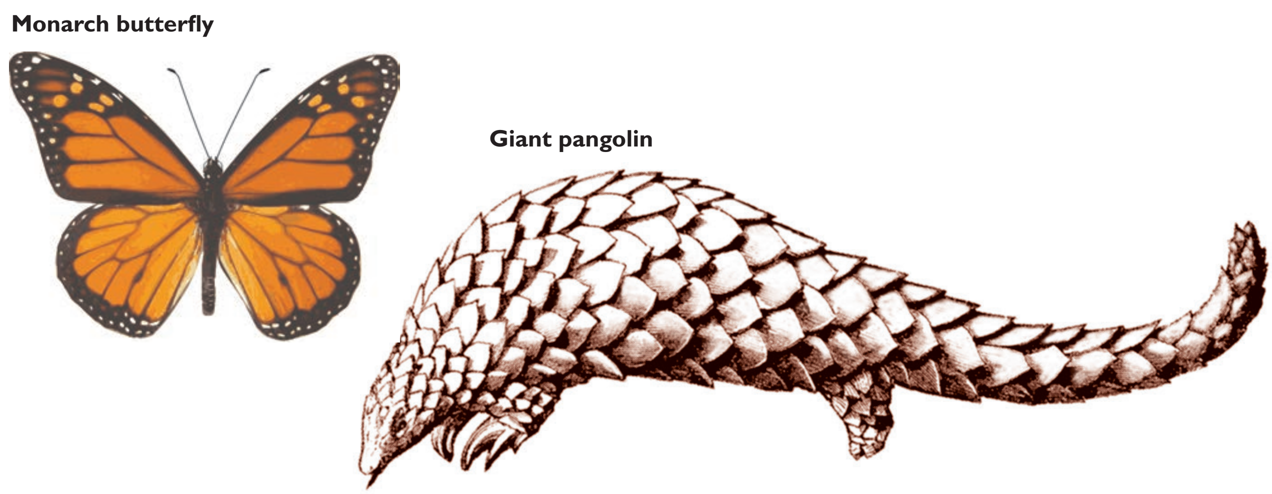
1.1 The table shows how two organisms – a monarch butterfly and a giant pangolin – are classified.

a Use the informatiton in the table to suggest whether these two organisms are not related at all, distantly related or closely related. Explain how you made your decision.

b Write down the genus of the giant pangolin.

c Use the Internet or a textbook to find out how a human is classified. Write it down in a table like the one shown on the right.

Kingdom	animal	animal
Phylum	arthropods	vertebrates
Class	insects	mammals
Order	Lepidoptera (butterflies and moths)	Pholidota
Family	Danaidae	Manidae
Genus	*Danaus*	*Manis*
Species	*Danaus plexippus*	*Manis gigantea*



1.3 The kingdoms of living organisms

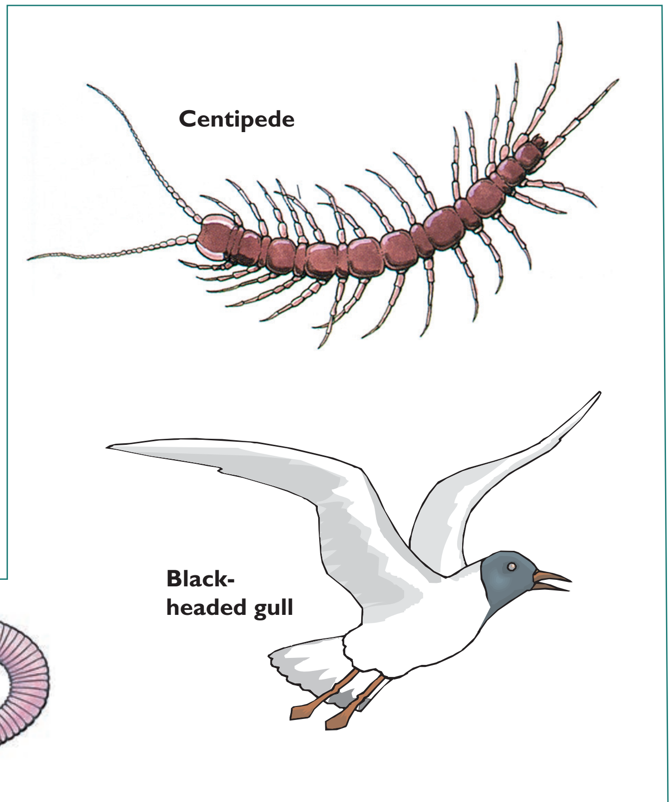
Animals

Animals (Figure **1.4**) are usually easy to recognise. Most animals can move actively, hunting for food. Under the microscope, we can see that their cells have no cell walls.

Some animals have, in the past, been confused with plants. For a very long time, sea anemones were classified as plants, because they tend to stay fixed in one place, and their tentacles look rather like flower petals. Now we know that they are animals.

Characteristics:

- multicellular (their bodies contain many cells)
- cells have a nucleus, but no cell walls or chloroplasts
- feed on organic substances made by other living organisms.



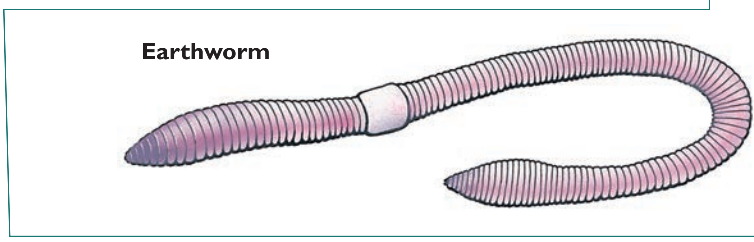


Figure 1.4 Some examples of animals.

Plants

The plants that are most familiar to us are the flowering plants, which include most kinds of trees. These plants have leaves, stems, roots and flowers (Figure **1.5**). However, there are other types of plants – including ferns and mosses – that do not have flowers. What all of them have in common is the green colour, caused by a pigment called chlorophyll. This pigment absorbs energy from sunlight, and the plant can use this energy to make sugars, by the process of photosynthesis.

As they do not need to move around to get their food, plants are adapted to remain in one place. They often have a spreading shape, enabling them to capture as much sunlight energy as possible.

Characteristics:

- multicellular
- cells have a nucleus, cell walls made of cellulose and often contain chloroplasts
- feed by photosynthesis
- may have roots, stems and leaves.

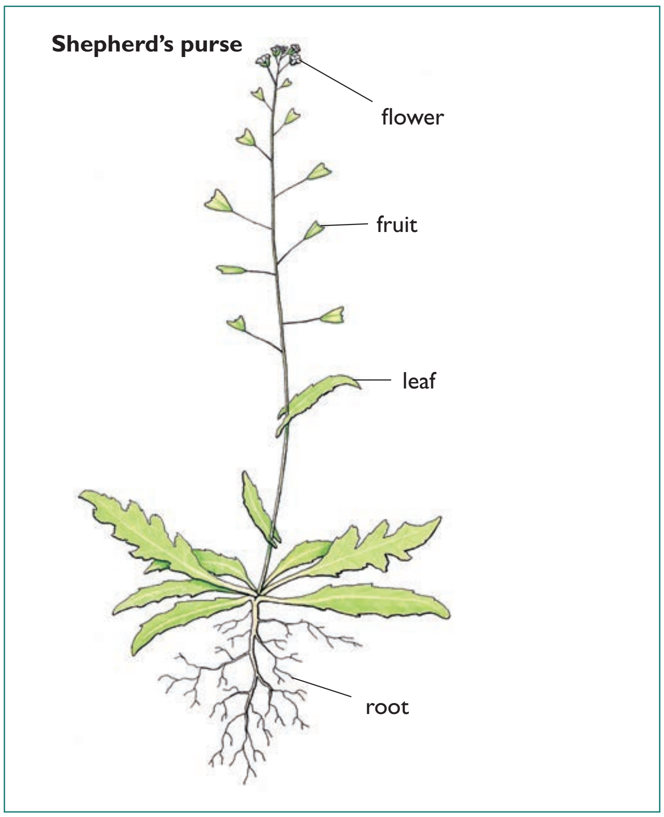


Figure 1.5. An example of a plant.

Questions

1.2 The photograph below shows a sea anemone.

a Explain why people used to think that sea anemones were plants.

b Explain how using a microscope could help you to confirm that sea anemones are animals.

1.3 The photograph below shows a plant called a liverwort. Liverworts do not have roots or proper leaves. They do not have flowers. Suggest how you could show that a liverwort belongs to the plant kingdom.

Fungi

For a very long time, fungi were classified as plants. However, we now know that they are really very different, and belong in their own kingdom. Figure **1.6** shows the characteristic features of fungi.

We have found many different uses to make of fungi. We eat them as mushrooms. We use the unusual fungus yeast to make ethanol and bread. We obtain antibiotics such as penicillin from various different fungi.

Some fungi, however, are harmful. Some of these cause food decay, while a few cause diseases, including ringworm and athlete's foot.

Fungi do not have chlorophyll and do not photosynthesise. Instead they feed saprophytically, or parasitically, on organic material like faeces, human foods and dead plants or animals.

Characteristics:

- usually multicellular (many-celled)
- have nuclei
- have cell walls, not made of cellulose
- do not have chlorophyll
- feed by saprophytic or parasitic nutrition.

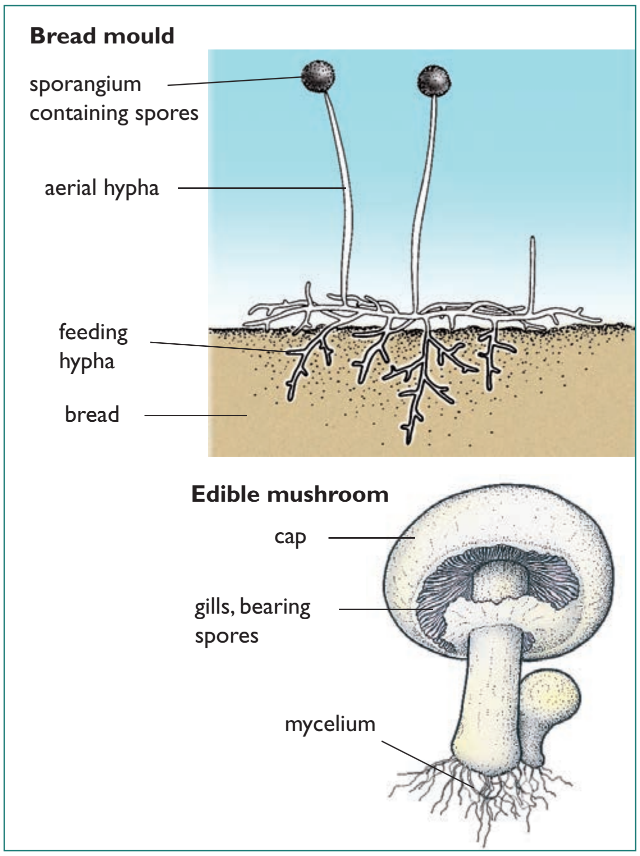


Figure 1.6 Some examples of fungi.

Protoctista

The kingdom Protoctista (Figure **1.7**) contains quite a mixture of organisms. They all have cells with a nucleus, but some have plant-like cells with chloroplasts and cellulose cell walls, while others have animal-like cells without these features. Most protoctists are unicellular (made of just a single cell) but some, such as seaweeds, are multicellular.

Characteristics:

- multicellular or unicellular
- cells have a nucleus
- cells may or may not have a cell wall and chloroplasts
- some feed by photosynthesis and others feed on organic substances made by other organisms.

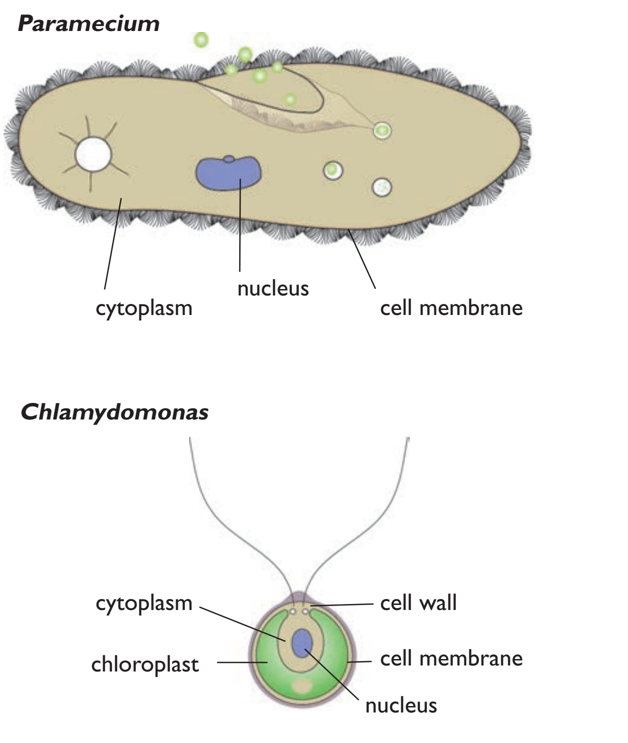


Figure 1.7 Some examples of protoctists.

Prokaryotes

Figure **1.8** shows some bacteria. Bacteria have cells that are very different from the cells of all other kinds of organism. The most important difference is that they do not have a nucleus.

You will meet bacteria at various stages in your biology course. Some of them are harmful to us and cause diseases such as tuberculosis (TB) and cholera. Many more, however, are helpful. You will find out about their useful roles in the carbon cycle and the nitrogen cycle, in biotechnology, in the treatment of sewage to make it safe to release into the environment and in making insulin for the treatment of people with diabetes.

Some bacteria can carry out photosynthesis. The oldest fossils belong to this kingdom, so we think that they were the first kinds of organism to evolve.

Characteristics:

- often unicellular (single-celled)
- have no nucleus
- have cell walls, not made of cellulose
- have no mitochondria.

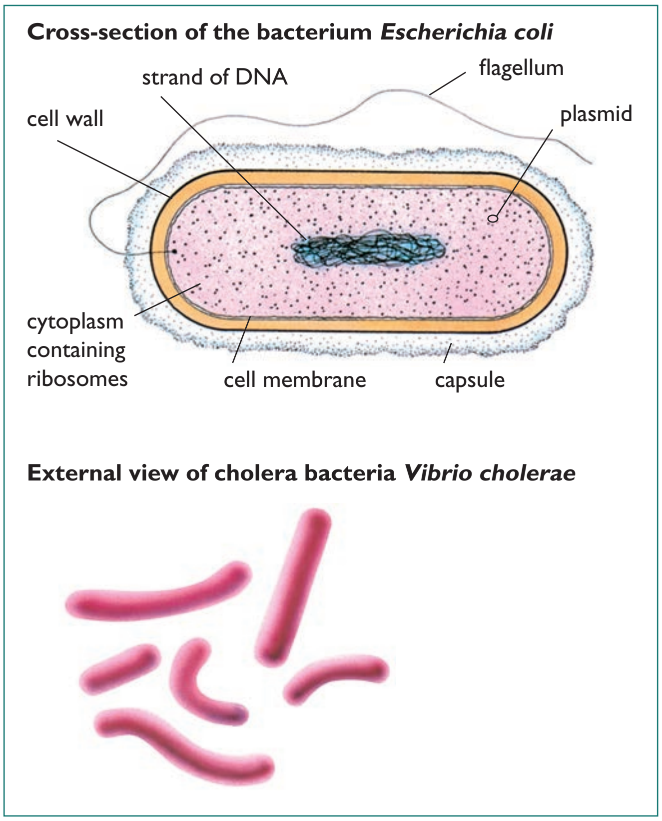


Figure 1.8 Some examples of bacteria.

1.4 Viruses

You have almost certainly had an illness caused by a virus. Viruses cause common diseases such as colds and influenza, and also more serious ones such as AIDS.

Viruses are not normally considered to be alive, because they cannot do anything other than just exist, until they get inside a living cell. They then take over the cell's machinery to make multiple copies of themselves. These new viruses burst out of the cell and invade others, where the process is repeated. The host cell is usually killed when this happens. On their own, viruses cannot move, feed, excrete, show sensitivity, grow or reproduce.

Figure **1.9** shows one kind of virus. It is not made of a cell – it is simply a piece of RNA (a chemical similar to DNA) surrounded by some protein molecules. It is hugely magnified in this diagram. The scale bar represents a length of 10 nanometres. One nanometre is 1×10^{-9} mm. In other words, you could line up more than 15 000 of these viruses between two of the millimetre marks on your ruler.

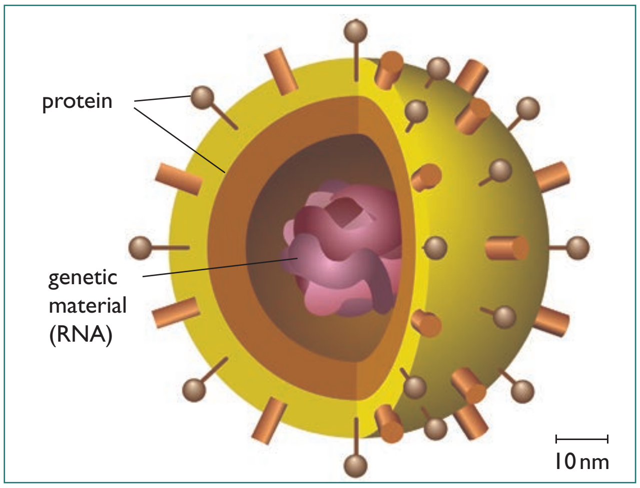


Figure 1.9 An influenza virus.

Questions

1.4 Why are viruses not generally considered to be living things?

1.5 State **one** similarity and **one** difference between the cells of a fungus and the cells of a plant.

1.6 How do the cells of bacteria differ from the cells of plants and animals?

1.5 Classifying animals

Figure **1.10** shows some of the major groups into which the animal kingdom is classified.

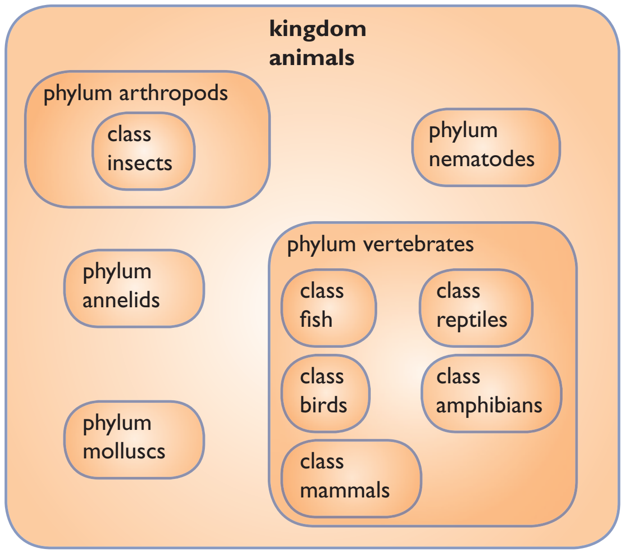


Figure 1.10 Classification of the animal kingdom.

Phylum Vertebrates

These are animals with a supporting rod running along the length of the body. The most familiar ones have a backbone and are called vertebrates.

Class Fish

The fish (Figure **1.11**) all live in water, except for one or two like the mudskipper, which can spend short periods of time breathing air.

Characteristics:

- vertebrates with scaly skin
- have gills
- have fins.

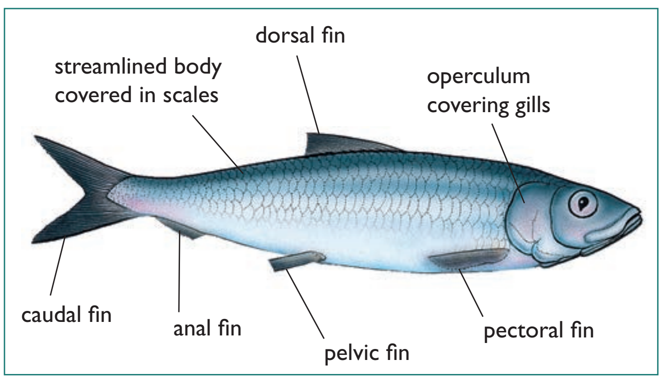


Figure 1.11 A fish.

Class Amphibians

Although most adult amphibians live on land, they always go back to the water to breed. Frogs, toads and salamanders are amphibians (Figure **1.12**).

Characteristics:

- vertebrates with moist, scale-less skin
- eggs laid in water, larva (tadpole) lives in water
- adult often lives on land
- larva has gills, adult has lungs.

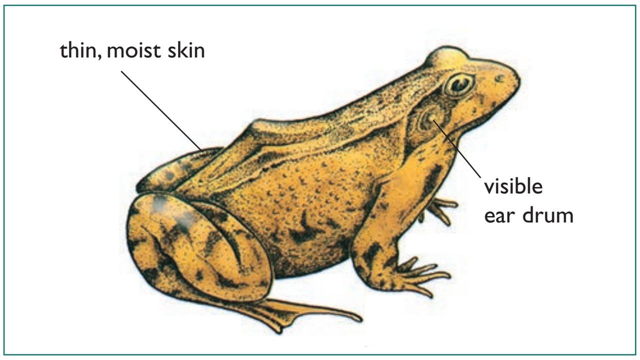


Figure 1.12 A frog.

Class Reptiles

These are the crocodiles, lizards, snakes, turtles and tortoises (Figure **1.13**). Reptiles do not need to go back to the water to breed because their eggs have a waterproof shell which stops them from drying out.

Characteristics:

- vertebrates with scaly skin
- lay eggs with rubbery shells.

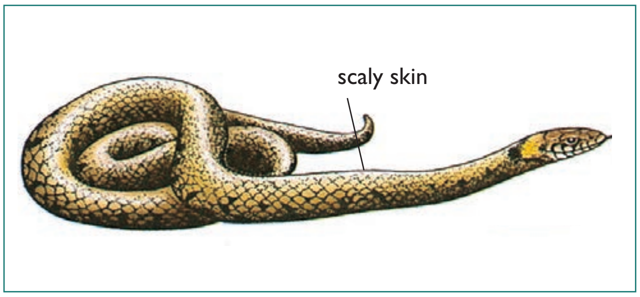


Figure 1.13 A snake.

Class Birds

The birds (Figure **1.14**), like reptiles, lay eggs with waterproof shells.

Characteristics:

- vertebrates with feathers
- forelimbs have become wings
- lay eggs with hard shells
- endothermic
- have a beak.

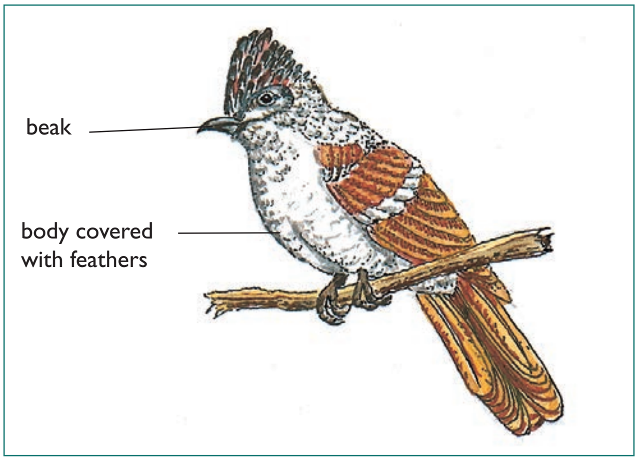


Figure 1.14 A bird.

Class Mammals

This is the group that humans belong to (Figure **1.15**).

Characteristics:

- vertebrates with hair
- have a placenta
- young feed on milk from mammary glands
- endothermic
- have a diaphragm
- heart has four chambers
- have different types of teeth (incisors, canines premolars and molars).

Figure 1.15 An ocelot, an example of a mammal.

Phylum Arthropods

Arthropods are animals with jointed legs, but no backbone. They are a very successful group, because they have a waterproof exoskeleton that has allowed them to live on dry land. There are more kinds of arthropod in the world than all the other kinds of animal put together.

Characteristics:

- several pairs of jointed legs
- exoskeleton.

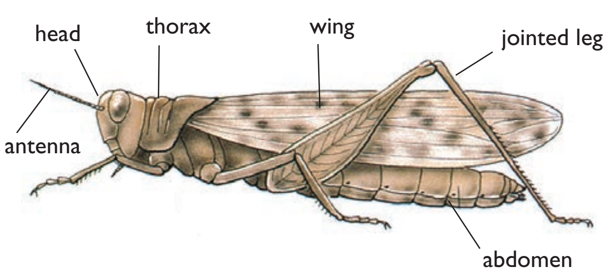
Insects

Insects (Figure **1.16**) are a very successful group of animals. Their success is mostly due to their exoskeleton and tracheae, which are very good at stopping water from evaporating from the insects' bodies, so they can live in very dry places. They are mainly terrestrial (land-living).

Characteristics:

- arthropods with three pairs of jointed legs
- two pairs of wings (one or both may be vestigial)
- breathe through tracheae
- body divided into head, thorax and abdomen.

Locust



Moth

Figure 1.16 Some examples of insects.

Crustaceans

These are the crabs, lobsters and woodlice. They breathe through gills, so most of them live in wet places and many are aquatic.

Characteristics:

- arthropods with more than four pairs of jointed legs
- not millipedes or centipedes
- breathe through gills.

Edible crab

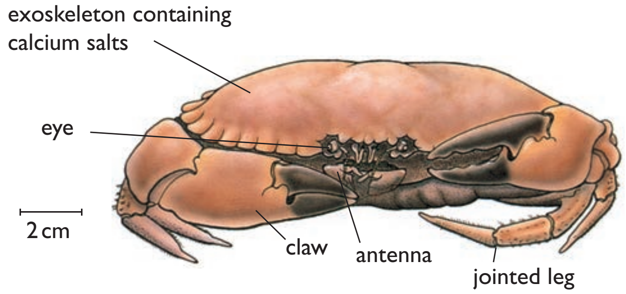


Figure 1.17 An example of a crustacean.

Arachnids

These are the spiders, ticks and scorpions. They are land-dwelling organisms.

Characteristics:

- arthropods with four pairs of jointed legs
- breathe through gills called book lungs.

Spider,

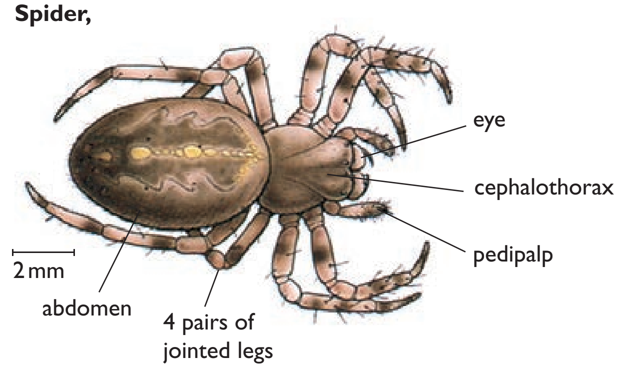


Figure 1.18 An example of an arachnid.

Myriapods

These are the centipedes and millipedes.

Characteristics:

- body consists of many segments
- each segment has jointed legs.

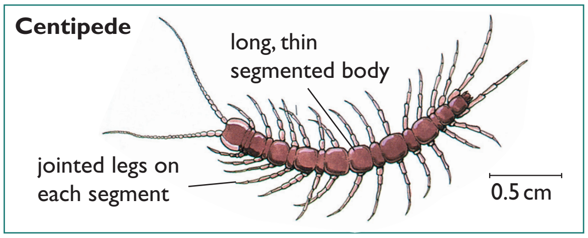


Figure 1.19 An example of a myriapod.

Questions

1.7 List **three** ways in which all mammals differ from all birds.

1.8 Explain why bats are classified as mammals, even though they have wings.

1.6 Classifying plants

We have seen that plants are organisms that have cells with cell walls made of cellulose. At least some parts of a plant are green. The green colour is caused by a pigment called chlorophyll, which absorbs energy from sunlight. The plant uses this energy to make glucose, using carbon dioxide and water from its environment. This is called photosynthesis.

Plants include small organisms such as mosses, as well as ferns (Figure **1.20**) and flowering plants (Figure 1.**21**).

Ferns

Ferns have leaves called fronds. They do not produce flowers, but reproduce by means of spores produced on the underside of the fronds.

Characteristics:

- plants with roots, stems and leaves
- have leaves called fronds
- do not produce flowers
- reproduce by spores

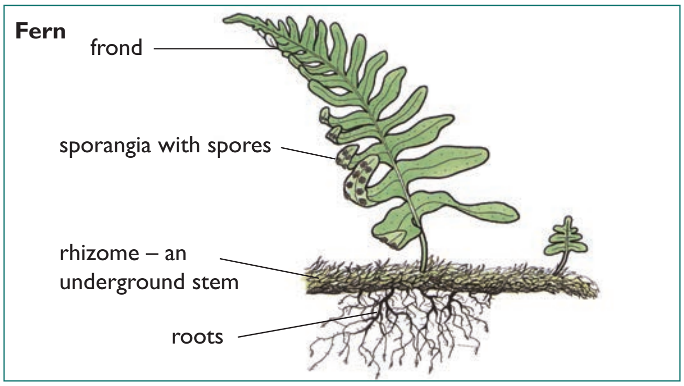


Figure 1.20 An example of a fern.

Flowering plants

These are the plants that are most familiar to us. They can be tiny, or very large – many trees are flowering plants.

Characteristics:

- plants with roots, stems and leaves
- reproduce by means of flowers and seeds
- seeds are produced inside the ovary, in the flower

Flowering plants can be divided into two main groups, the monocotyledonous plants and the dicotyledonous plants, often abbreviated to monocots and dicots (Figure **1.21**). Monocots have only one cotyledon in their seeds. They usually have a branching root system, and often have leaves in which the veins run in parallel to one another. Dicots have two cotyledons in their seeds. They frequently have a tap root system, and their leaves are often broader than those of monocots, and have a network of branching veins.

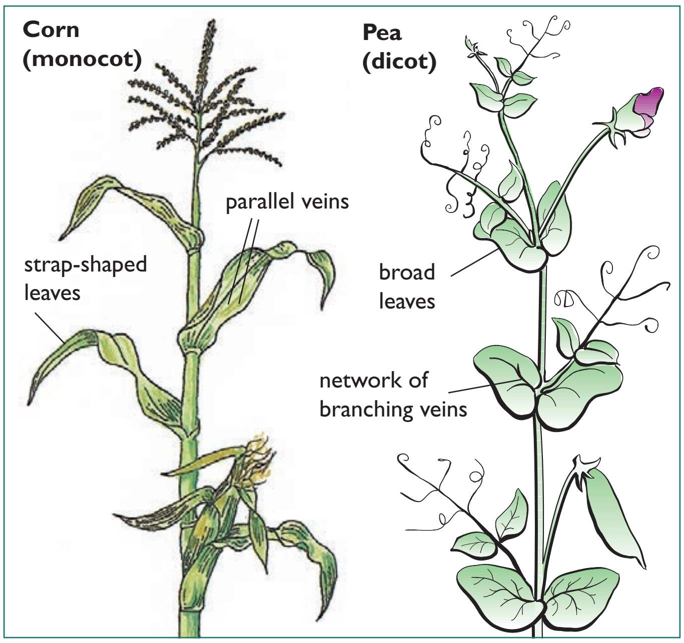


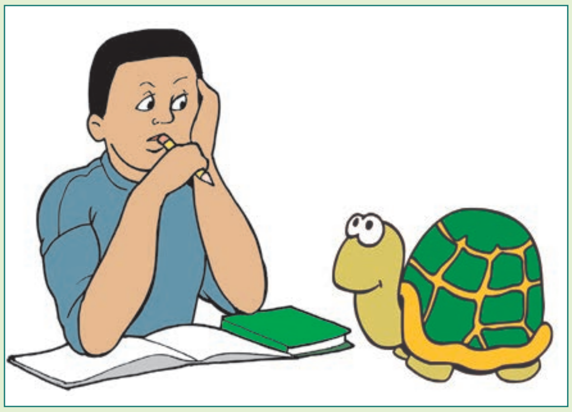
Figure 1.21 Flowering plants.

Activity 1.1
Making biological drawings

Skill
AO3.3 Observing, measuring and recording

Biologists need to be able to look closely at specimens – which might be whole organisms, or just part of an organism – and note significant features of them. It is also important to be able to make simple drawings to record these features. You don't have be good at art to be good at biological drawings. A biological drawing needs to be simple but clear.

You will be provided with a specimen of an animal to draw.



1 Look carefully at the specimen, and decide what group of animals it belongs to. Jot down the features of the organism that helped you to classify it.
2 Make a large, clear drawing of your organism.

Here are some points to bear in mind when you draw.

- Make good use of the space on your sheet of paper – your drawing should be large. However, do leave space around it so that you have room for labels.
- Always use a sharp HB pencil and have a good eraser with you.
- Keep all lines single and clear.
- Don't use shading unless it is absolutely necessary.
- Don't use colours.
- Take time to get the outline of your drawing correct first, showing the right proportions.
- Now label your drawing to show the features of the organism that are characteristic of its classification group. You could also label any features that help the organism to survive in its environment. These are called **adaptations**. For example, if your organism is a fish, you could label 'scales overlapping backwards, to provide a smooth, streamlined surface for sliding through the water'.

Here are some points to bear in mind when you label a diagram.

- Use a ruler to draw each label line.
- Make sure the end of the label line actually touches the structure being labelled.
- Write the labels horizontally.
- Keep the labels well away from the edges of your drawing.

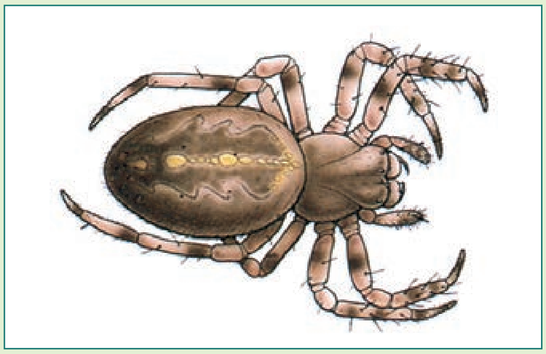
Activity 1.2
Calculating magnification

Skill
AO3.3 Observing, measuring and recording

Drawings of biological specimens are usually made at a different size from the real thing. It is important to show this on the diagram.
The magnification of a diagram is how much larger it is than the real thing.

$$\text{magnification} = \frac{\text{size of drawing}}{\text{size of real object}}$$

For example, measure the length of the spider's body in the diagram below. You should find that it is 40 mm long.



The real spider was 8 mm long. So we can calculate the magnification like this:

$$\text{magnification} = \frac{\text{length in drawing}}{\text{length of real spider}}$$

$$= \frac{40}{8}$$

$$= \times 5$$

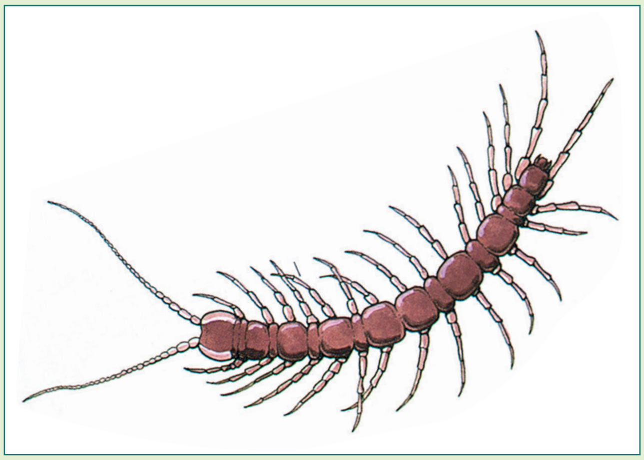
The following are two very important things to notice.

- You must use the same units for all the measurements. Usually, millimetres are the best units to use.
- You should not include any units with the final answer. Magnification does not have a unit. However, you *must* include the 'times' sign. If you read it out loud, you would say 'times five'.

Questions

A1 Measure the length of the lowest 'tail' (it is really called an appendage) on the centipede below. Write your answer in millimetres.

A2 The real length of the appendage was 10 mm. Use this, and your answer to question **A1**, to calculate the magnification of the drawing of the centipede.



Study tip

Be prepared to use the magnification equation organised in a different way:
size of real object = size of drawing × magnification.

1.7 Keys

If you want to identify an organism whose name you do not know, you may be able to find a picture of it in a book. However, not every organism may be pictured, or your organism may not look exactly like any of the pictures. If this happens, you can often find a **key** that you can use to work out what your organism is.

A key is a way of leading you through to the name of your organism by giving you two descriptions at a time, and asking you to choose between them. Each choice you make then leads you on to another pair of descriptions, until you end up with the name of your organism. This kind of key is called a **dichotomous** key. 'Dichotomous' means 'branching into two', and refers to the fact that you have **two** descriptions to choose from at each step.

Here is a key that you could use to identify the organisms shown in Figure **1.22**.

1	jointed limbs	**2**
	no jointed limbs	earthworm
2	more than 5 pairs of jointed limbs	centipede
	5 or fewer pairs of jointed limbs	**3**
3	first pair of limbs form large claws	crab
	no large claws	**4**
4	3 pairs of limbs	locust
	4 pairs of limbs	spider

To use the key, pick **one** of the animals that you are going to identify. Let's say you choose organism **B**. Decide which description in step **1** matches your organism. It has jointed limbs, so the key tells us to go to step **2**. Decide which description in step **2** matches organism **B**. It has more than 5 pairs of jointed limbs, so it is a centipede.

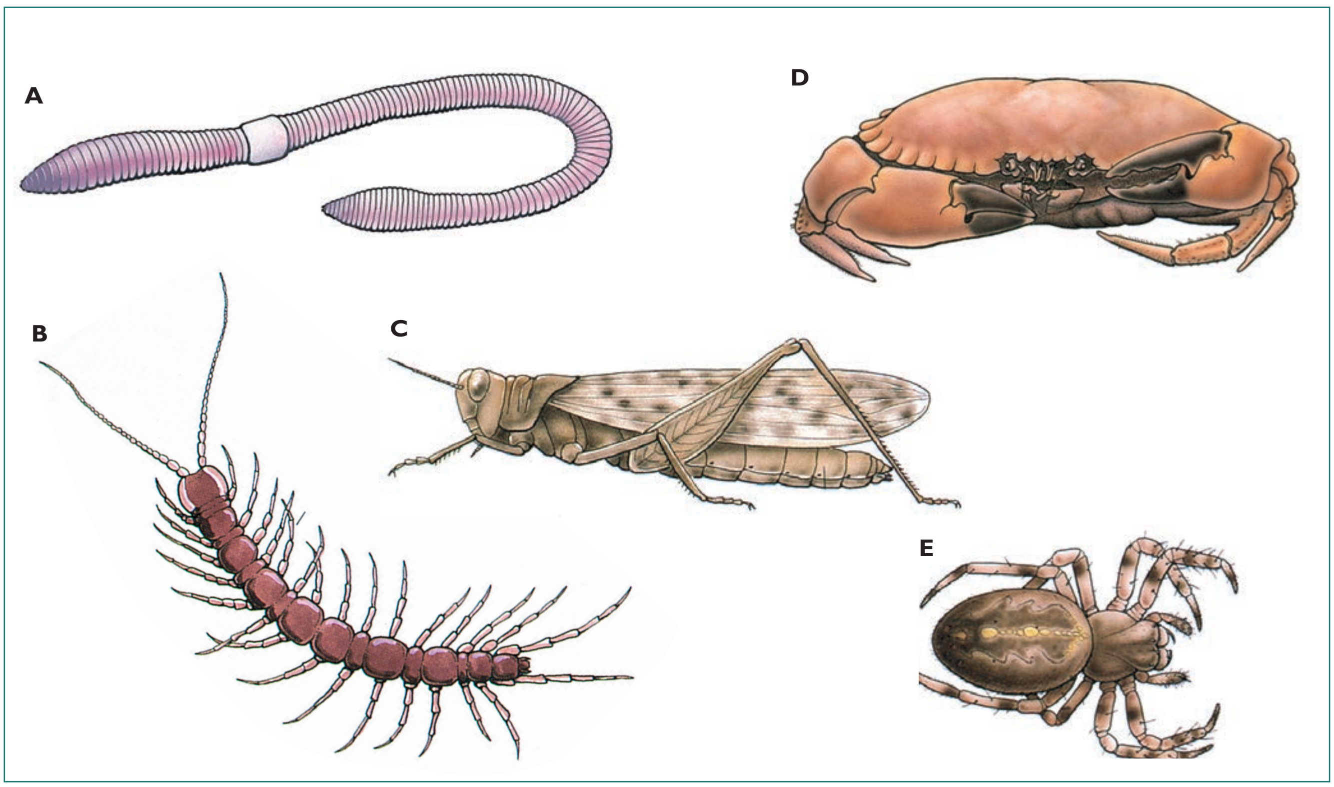


Figure 1.22 Organisms for practising using a key.

Constructing keys

Using a key is quite easy, but writing your own key is much more of a challenge.

Let's say you want to write a key to enable someone to identify each of the four flowers in Figure **1.20**.

First, make a list of features that clearly vary between the flowers. They should be features that cannot possibly be mistaken. Remember that the person using the key will probably only have one of the flowers to look at, so they cannot necessarily compare it with another kind of flower. So the number of petals or the colour is a good choice, but the size (large or small) is not, because different people might have different ideas about what is 'large' or 'small'.

Now choose one of these features that can split the flowers into two groups. The two groups don't have to be the same size – you could have two in one group and two in the other, or perhaps one in one group and the rest in the other.

Now concentrate on a group that contains more than one flower. Choose another feature that will allow you to split the flowers into two further groups.

Keep doing this until each 'group' contains only one flower.

Now go back and refine your key. Think carefully about the wording of each pair of statements. Make sure that each pair is made up of two clear alternatives. Try to reduce your key to the smallest possible number of statement pairs.

Finally, try your key out on a friend. If they have any problems with it, then try to reword or restructure your key to make it easier to use.

Figure 1.23 Can you write a key to identify these flowers?

Summary

You should know:

- the seven characteristics that distinguish living things from non-living objects
- why it is important to classify organisms
- about the binomial system of naming organisms
- S how DNA base sequences help with classification
- the characteristic features of animals (including arthropods and vertebrates) and plants
- S the features of bacteria, fungi and protoctists, and the problems of classifying viruses
- how to make good biological drawings and calculate magnification
- how to use a dichotomous key to identify an unknown organism
- how to construct a dichotomous key.

End-of-chapter questions

1 a Without looking back at the beginning of this chapter, decide which **five** of these characteristics are found in all living things.

movement	blood system	sight	growth	photosynthesis
nutrition	sensitivity	speech	excretion	

b List the other **two** characteristics of all living organisms.

2 Three species of tree have the following binomials: *Carpodiptera africana, Commiphora africana, Commiphora angolensis*

Which **two** of these species do biologists consider to be the most closely related? Explain your answer.

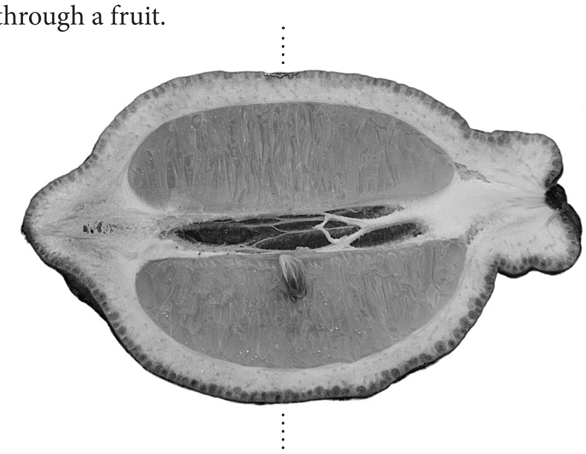
3 Construct a table to compare the characteristic features of animals and plants.

S 4 Construct a dichotomous key to help someone to identify **five** of your teachers. Try to meet these criteria:

- each pair of characteristics describes one contrasting feature
- each person could be identified without having to compare them with another person
- the key contains no more than four pairs of points (you may be able to do it with just three pairs).

When you have finished, swap your key with someone else to check if it works. If not, make adjustments to it.

5 The photograph shows a section through a fruit.

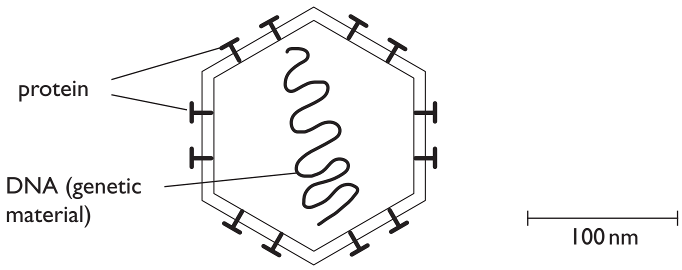


Magnification ×0.6

a Make a large diagram of the fruit. You do not need to label your diagram. [5]

b Calculate the diameter of the actual fruit at the point indicated by the dotted line. Show your working, and remember to include the unit. [3]

S 6 The diagram shows a virus.



a With reference to the diagram, and your own knowledge, discuss whether or not viruses can be considered to be living organisms. [5]

b 1 nm (nanometre) is 10^{-9} m. Measure the length of the scale bar. Use this, and the label on the scale bar, to calculate the magnification of the diagram. Show your working. [3]

2 Cells

In this chapter, you will find out about:

- the structure of plant cells and animal cells
- the functions of the different parts of cells
- tissues, organs and organ systems.

Cells from deep time

If a long, thin spike of limestone hanging down from the roof of a cave is called a stalactite, what do you call a long, thin drip of bacteria-filled slime?

Caver Jim Pisarowicz decided to call them snottites, and the name stuck (Figure **2.1**). Snottites are studied by biologists interested in organisms that can live in environments so strange that almost nothing else can live there. These organisms are called extremophiles, which means 'lovers of extreme conditions'.

Snottites are found in caves where the atmosphere contains large amounts of the smelly, toxic gas hydrogen sulfide. The bacteria in the slimy threads, far from being poisoned by the gas, actually use it to make their food. In the middle of the threads, there is virtually no oxygen, yet some kinds of bacteria live even here.

Similar conditions – a lot of hydrogen sulfide, almost no oxygen – were found in the Earth's very early atmosphere, more than 3.5 billion years ago, and this is probably when these extremophile bacteria first evolved. At that time, the cells of all organisms were much less complex than those of plants and animals (which did not appear on Earth until around 2 billion years ago). They had no nucleus, for example. Yet bacteria made of these seemingly simple cells are clearly very successful, if they have managed to survive almost unchanged through such an unimaginably long period of time.

Figure 2.1 Snottites hanging from the roof of a cave.

2.1 Cell structure

All organisms are made of cells. Cells are very small, so large organisms contain millions of cells. Some organisms are **unicellular**, which means that they are made of just a single cell. Bacteria and yeast are examples of single-celled organisms.

Microscopes

To see cells clearly, you need to use a microscope (Figure **2.2**). The kind of microscope used in a school laboratory is called a **light microscope** because it shines light through the piece of animal or plant you are looking at. It uses glass lenses to magnify and focus the image. A very good light microscope can magnify about 1500 times, so that all the structures in Figures **2.3** and **2.4** can be seen.

Photomicrographs of plant and animal cells are shown in Figure **2.5** and Figure **2.6**. A photomicrograph is a picture made using a light microscope.

To see even smaller things inside a cell, an electron microscope is used. This uses a beam of electrons instead of light, and can magnify up to 500 000 times. This means that a lot more detail can be seen inside a cell. We can see many structures more clearly, and also some structures that could not be seen at all with a light microscope.

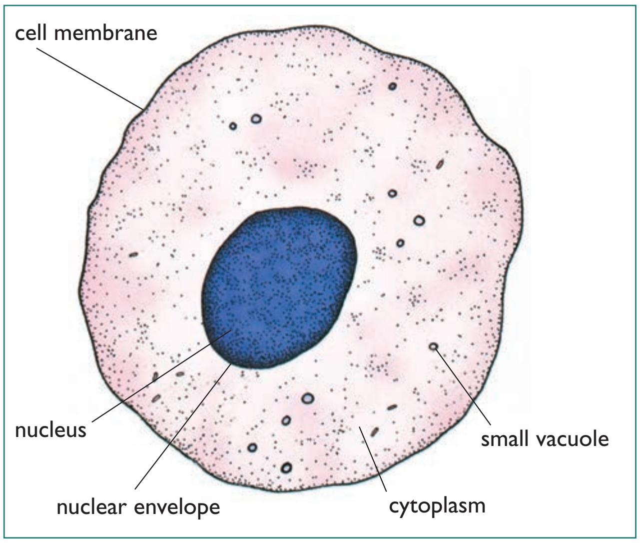


Figure 2.3 A typical animal cell – a liver cell – as seen with a light microscope.

Questions

2.1 How many times can a good light microscope magnify?

2.2 If an object was 1mm across, how big would it look if it was magnified 10 times?

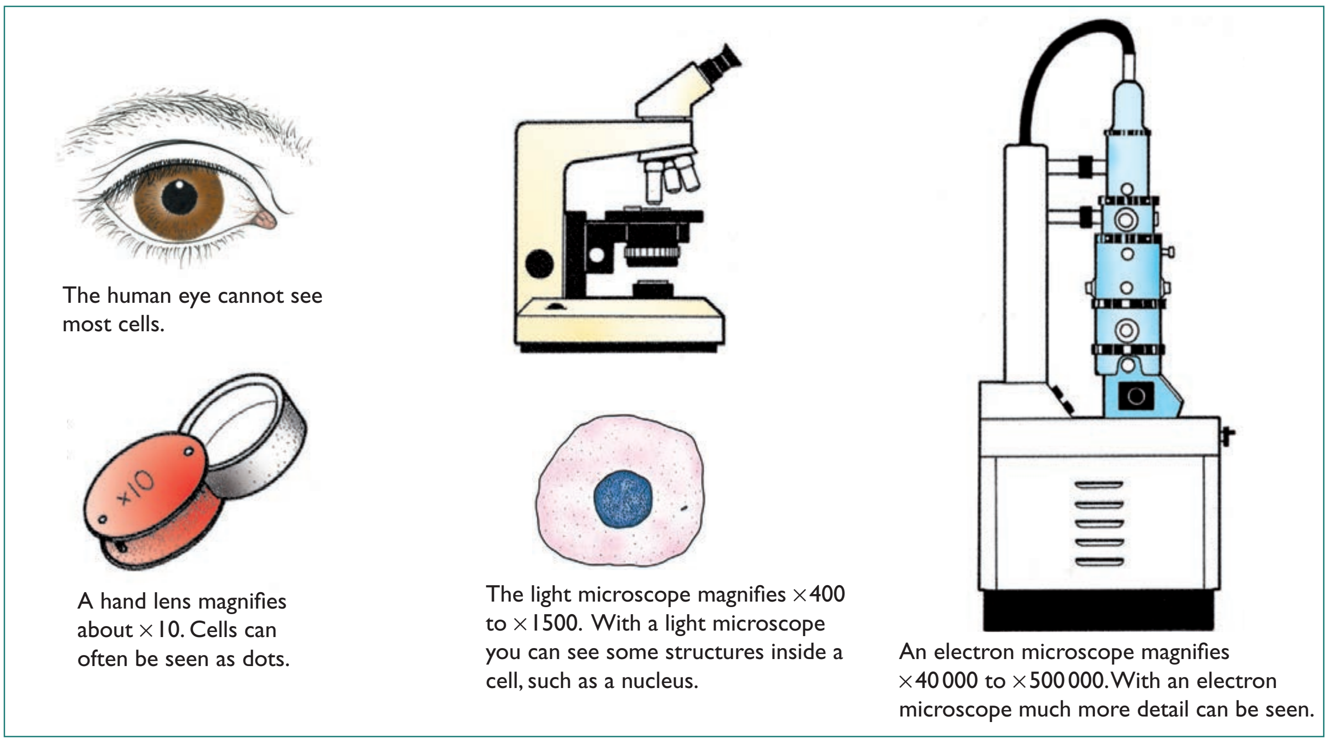


Figure 2.2 Equipment used for looking at biological material.

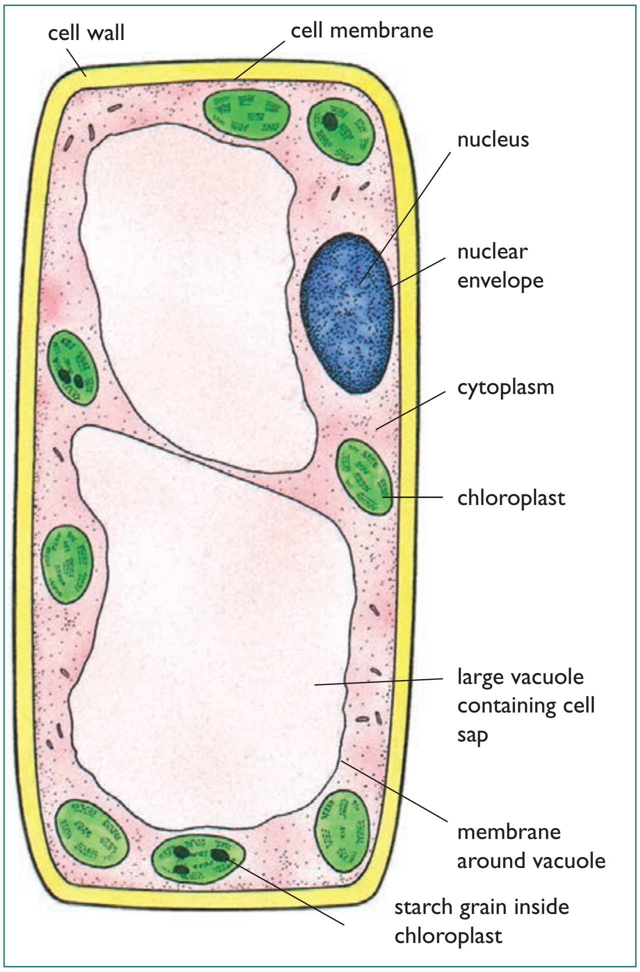


Figure 2.4 A typical plant cell – a palisade mesophyll cell – as seen with a light microscope.

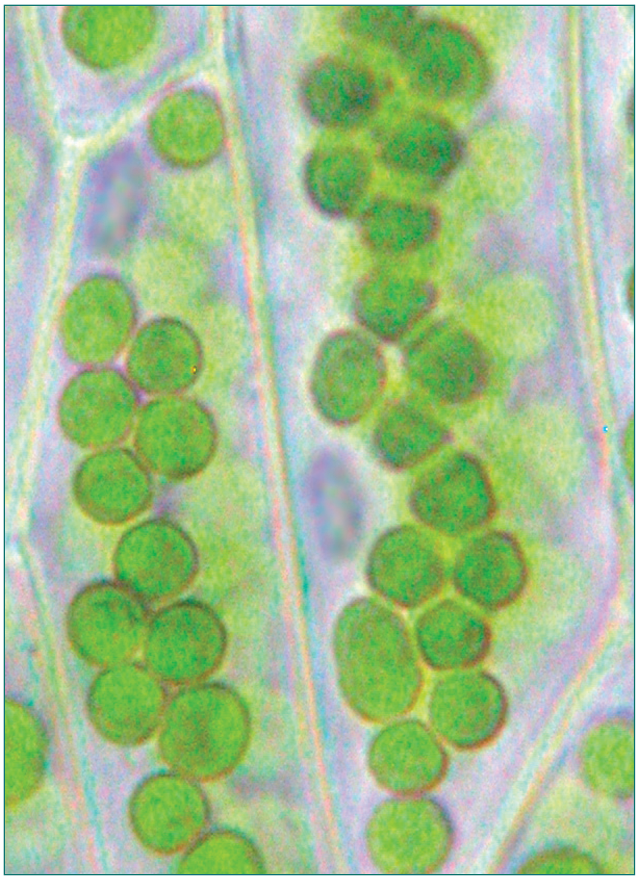


Figure 2.5 Many plant cells contain green structures, called chloroplasts. Even if it does not have any chloroplasts, you can still identify a plant cell because it has a cell wall around it (×2000).

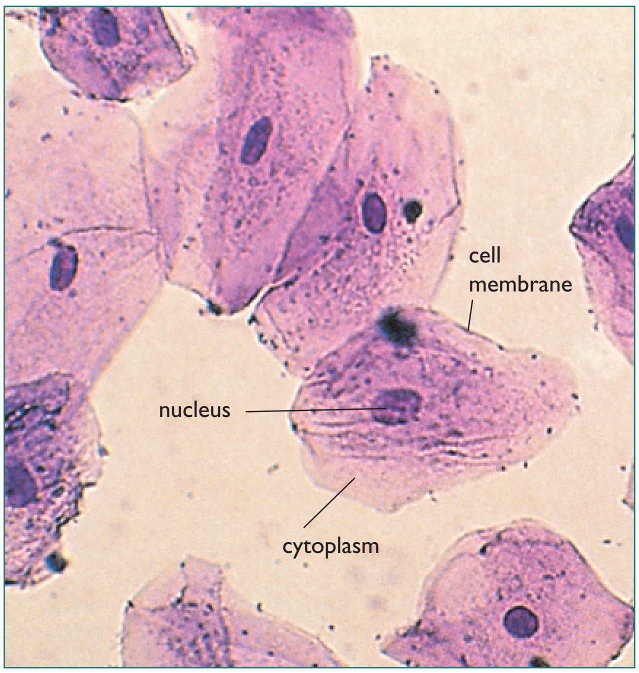


Figure 2.6 Cells from the trachea (windpipe) of a mammal, seen through a light microscope (×300).

Cell membrane

Whatever sort of animal or plant they come from, all cells have a **cell membrane** (sometimes called the cell surface membrane) around the outside. Inside the cell membrane is a jelly-like substance called **cytoplasm**, in which are found many small structures called **organelles**. The most obvious of these organelles is usually the **nucleus**. In a plant cell, it is very difficult to see, because it is right against the cell wall.

The cell membrane is a very thin layer of protein and fat. It is very important to the cell because it controls what goes in and out of it. It is said to be **partially permeable**, which means that it will let some substances through but not others.

Cell wall

All plant cells are surrounded by a cell wall made mainly of **cellulose**. Paper, which is made from cell walls, is also made of cellulose. Animal cells never have cell walls made of cellulose. Cellulose belongs to a group of substances called polysaccharides, which are described in Chapter **4**. Cellulose forms fibres which criss-cross over one another to form a very strong covering to the cell (Figure **2.7**). This helps to protect and support the cell. If the cell absorbs a lot of water and swells, the cell wall stops it bursting.

Because of the spaces between fibres, even very large molecules are able to go through the cellulose cell wall. It is therefore said to be **fully permeable**.

Cytoplasm

Cytoplasm is a clear jelly. It is nearly all water; about 70% is water in many cells. It contains many substances dissolved in it, especially proteins. Many different **metabolic reactions** (the chemical reactions of life) take place in the cytoplasm.

Vacuoles

A vacuole is a space in a cell, surrounded by a membrane, and containing a solution. Plant cells have very large vacuoles, which contain a solution of sugars and other substances, called **cell sap**. A full vacuole presses outwards on the rest of the cell, and helps to keep it in shape. S Animal cells have much smaller membrane-bound spaces, called **vesicles**, which may contain food or water.

Figure 2.7 Cellulose fibres from a plant cell wall. This picture was taken using an electron microscope (×50 000).

Chloroplasts

Chloroplasts are never found in animal cells, but most of the cells in the green parts of plants have them. They contain the green colouring or pigment called **chlorophyll**. Chlorophyll absorbs energy from sunlight, and this energy is then used for making food for the plant by **photosynthesis** (Chapter **6**).

Chloroplasts often contain starch grains, which have been made by photosynthesis. Animal cells never contain starch grains. Some animal cells, however, do have granules (tiny grains) of another substance similar to starch, called **glycogen**. These granules are found in the cytoplasm, not inside chloroplasts.

Nucleus

The nucleus is where the genetic information is stored. This helps the cell to make the right sorts of proteins. The information is kept on the **chromosomes**, which are inherited from the organism's parents. The chromosomes are made of **DNA**.

Chromosomes are very long, but so thin that they cannot easily be seen even using the electron microscope. However, when the cell is dividing, they become short and thick, and can be seen with a good light microscope.

Table **2.1** compares some features of plant cells and animal cells.

Plant cells	Animal cells
have a cellulose cell wall outside the cell membrane	have no cell wall
have a cell membrane	have a cell membrane
have cytoplasm	have cytoplasm
have a nucleus	have a nucleus
often have chloroplasts containing chlorophyll	have no chloroplasts
often have large vacuoles containing cell sap	have only small vacuoles
often have starch grains	never have starch grains; sometimes have glycogen granules
often regular in shape	often irregular in shape

Table 2.1 A comparison of plant and animal cells.

Mitochondria

Photographs of cells taken using an electron microscope, called electronmicrographs, show tiny structures that are almost invisible with a light microscope. They are called **mitochondria** (singular: mitochondrion). Mitochondria are found in almost all cells, except those of prokaryotes. Figures **2.8** and **2.9** show electronmicrographs of mitochondria.

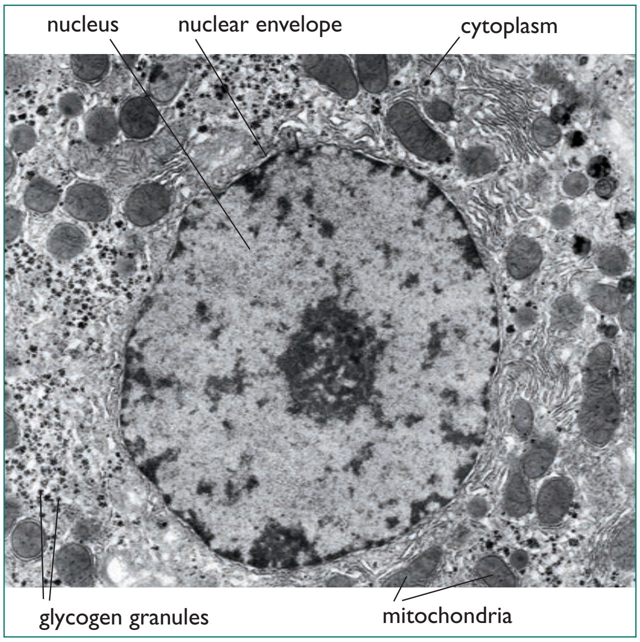


Figure 2.8 Part of a liver cell seen using an electron microscope (×20 000).

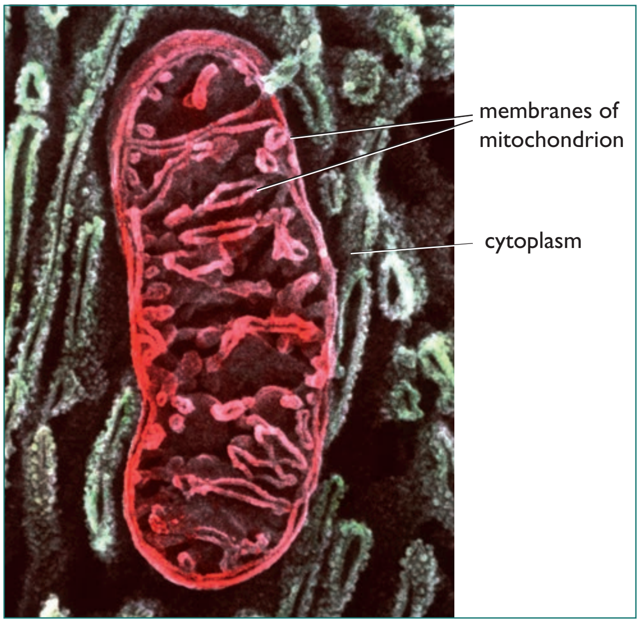


Figure 2.9 Close-up of a mitochondrion. Electron microscopes only show images in black and white, so this photo has been artificially coloured (×30 000).

Mitochondria are the powerhouses of the cell. Inside them, oxygen is used to release energy from glucose, in the process called aerobic respiration. You will find out more about aerobic respiration in Chapter **11**.

Not surprisingly, cells that use a lot of energy have a lot of mitochondria. Muscle cells, for example, are tightly packed with mitochondria. Sperm cells, which need energy to swim to the egg, and neurones (nerve cells), which need energy to transmit impulses, also have large numbers of mitochondria.

The black spots in the electron micrograph in Figure **2.8** are granules of a carbohydrate called glycogen. This is similar to starch. (Starch is never found in animal cells – they store glycogen instead.) Glycogen is a reserve fuel. When required, it can be broken down to glucose, to be used as a fuel by the mitochondria in the liver cell, or transported in the blood to other cells that need it.

Ribosomes

Even tinier structures than mitochondria can just be seen with an electron microscope (Figure **2.10**). They are called **ribosomes**. They look like tiny dots attached to a network of membranes that runs throughout the cytoplasm. This network is called the **rough endoplasmic reticulum**. Ribosomes may also just be scattered freely in the cytoplasm. Ribosomes are found in all types of cells – bacteria, protoctists, fungi, animals and plants all have ribosomes in their cells.

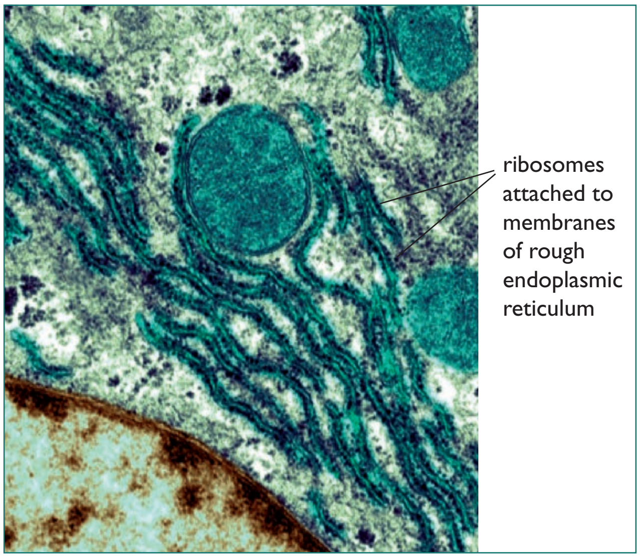


Figure 2.10 You can just make out tiny ribosomes attached to the membranes in this electron micrograph of a cell (×30 000).

Although they are so tiny that we can scarcely see them even with an electron microscope, ribosomes have a very important function in a cell. They are the places where proteins are made, by joining amino acids together in a long chain. This is done according to instructions carried on the DNA in the cell's nucleus, which specify the sequence of amino acids that should be strung together to make a particular protein. You can read more about this in Chapter **4**.

Micrometres

Cells, and structures inside them such as mitochondria and ribosomes, are so small that we need a very small unit in which to measure them. The most useful one is the **micrometre**, symbol μm.

$1\,\mu m = 1 \times 10^{-6}\,m$

$1\,m = 10^{6}\,\mu m$

Questions

2.3 How many micrometres are there in 1 cm?

2.4 How many micrometres are there in 1 mm?

2.5 The mitochondrion in Figure **2.9** is magnified 20 000 times.

a Using a ruler, carefully measure the maximum length of the mitochondrion. Record your measurement in mm (millimetres).

b Convert your answer to μm (micrometres).

c Use the formula:

$$\text{real size in } \mu m = \frac{\text{size of the image in } \mu m}{\text{magnification}}$$

to calculate the real size of the mitochondrion in μm.

d How many of these mitochondria could you line up end to end between two of the mm marks on your ruler?

Activity 2.1
Using a microscope

Practise using a microscope to look at very small things.

Activity 2.2
Looking at animal cells

Skills

AO3.1 Using techniques, apparatus and materials

AO3.3 Observing, measuring and recording

⚠ Wash your hands thoroughly after handling the trachea and cells.

Some simple animal cells line the mouth and trachea (or windpipe). If you colour or stain the cells, they are quite easy to see using a light microscope (see Figure **2.6** and Figure **2.11**).

1 Using a section lifter, gently rub off a little of the lining from the inside of the trachea provided.

2 Put your cells onto the middle of a clean microscope slide, and gently spread them out. You will probably not be able to see anything at all at this stage.

3 Put on a few drops of methylene blue.

4 Gently lower a coverslip over the stained cells, trying not to trap any air bubbles.

5 Use filter paper or blotting paper to clean up the slide, and then look at it under the low power of a microscope.

6 Make a labelled drawing of a few cells.

Questions

A1 Which part of the cell stained the darkest blue?

A2 Is the cell membrane permeable or impermeable to methylene blue? Explain how you worked out your answer.

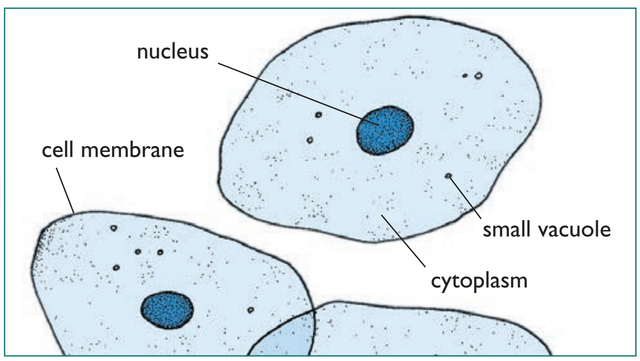


Figure 2.11 A drawing of tracheal cells seen through a light microscope.

Activity 2.3
Looking at plant cells

Skills
AO3.1 Using techniques, apparatus and materials
AO3.3 Observing, measuring and recording

⚠ Take care with the sharp blade when cutting the onion.

To be able to see cells clearly under a microscope, you need a very thin layer. It is best if it is only one cell thick. An easy place to find such a layer is inside an onion bulb.

1 Cut a small piece from an onion bulb, and use forceps to peel a small piece of thin skin, called epidermis, from the inside of it. Do not let it get dry.
2 Put a drop or two of water onto the centre of a clean microscope slide. Put the piece of epidermis into it, and spread it flat.
3 Gently lower a coverslip onto it.
4 Use filter paper or blotting paper to clean up the slide, and then look at it under the low power of a microscope.
5 Make a labelled drawing of a few cells. Figure **2.12** may help you, but do not just copy it. Do remember not to colour your drawing.
6 Using a pipette, take up a small amount of iodine solution. Very carefully place some iodine solution next to the edge of the coverslip. The iodine solution will seep under the edge of the coverslip. To help it do this, you can place a small piece of filter paper next to the opposite side of the coverslip, which will soak up some of the liquid and draw it through.
7 Look at the slide under the low power of the microscope. Note any differences between what you can see now and what it looked like before adding the iodine solution.

Questions

A1 Name **two** structures which you can see in these cells, but which you could not see in the tracheal cells (Activity **2.2**).
A2 Most plant cells have chloroplasts, but these onion cells do not. Suggest a reason for this.
A3 Iodine solution turns blue-black in the presence of starch. Did any of the onion cells contain starch?

Questions

2.6 What sort of cells are surrounded by a cell membrane?
2.7 What are plant cell walls made of?
2.8 What does fully permeable mean?
2.9 What does partially permeable mean?
2.10 What is the main constituent of cytoplasm?
2.11 What is a vacuole?
2.12 What is cell sap?
2.13 Chloroplasts contain chlorophyll. What does chlorophyll do?
2.14 What is stored in the nucleus?
2.15 Why can chromosomes be seen only when a cell is dividing?

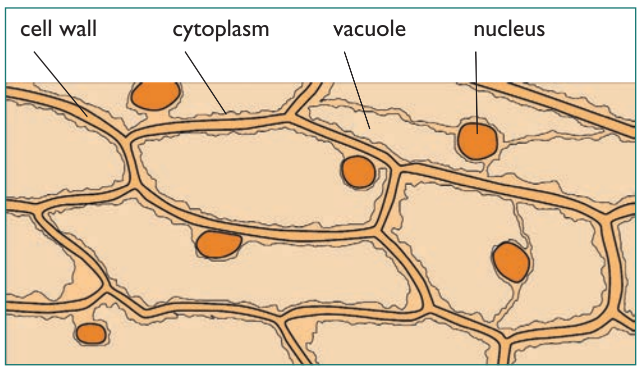


Figure 2.12 A drawing of onion epidermis cells seen through a light microscope after staining with iodine.

Questions

S

2.16 Which types of cells contain mitochondria?
2.17 Outline the function of mitochondria.
2.18 Which types of cells contain ribosomes?
2.19 Outline the function of ribosomes.

2.2 Cells and organisms

A large organism such as yourself may contain many millions of cells, but not all the cells are alike. Almost all of them can carry out the activities which are characteristic of living things, but many of them specialise in doing some of these better than other cells do. Muscle cells, for example, are specially adapted for movement. Most cells in the leaf of a plant are specially adapted for making food by photosynthesis.

Table **2.2** lists examples of specialised cells, and the parts of the book where you will find information about how their structures help them to carry out their functions.

Tissues

Often, cells which specialise in the same activity are found together. A group of cells like this is called a **tissue**. An example of a tissue is a layer of cells lining your stomach. These cells make enzymes to help to digest your food (Figure **2.13**).

The stomach also contains other tissues. For example, there is a layer of muscle in the stomach wall, made of cells which can move. This muscle tissue makes the wall of the stomach move in and out, churning the food and mixing it up with the enzymes.

Plants also have tissues. You may already have looked at some epidermis tissue from an onion bulb. Inside a leaf, a layer of cells makes up the palisade tissue, in which the cells are specialised to carry out photosynthesis.

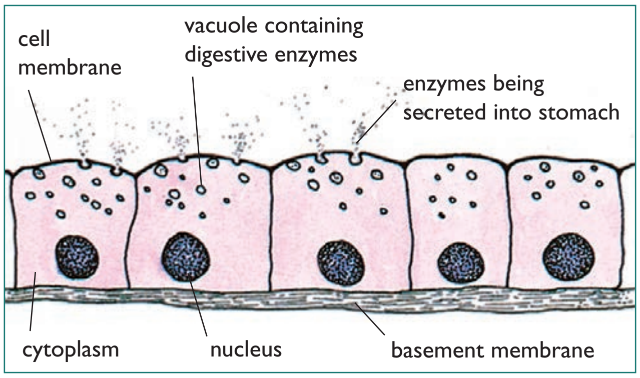


Figure 2.13 Cells lining the stomach – an example of a tissue.

Organs

All tissues in the stomach work together, although each has its own job to do. A group of tissues like this makes up an **organ**. The stomach is an organ. Other organs include the heart, the kidneys and the lungs.

In a plant, an onion bulb is an organ. A leaf is another example of a plant organ.

Organ systems

The stomach is only one of the organs which help in the digestion of food. The mouth, the intestines and the stomach are all part of the digestive system. The heart is part of the circulatory system, while each kidney is part of the excretory system.

The way in which organisms are built up can be summarised like this: cells make up tissues, which make up organs, which make up **organ systems**, which make up organisms. For example, the ciliated cells in Figure **2.14** make up a tissue that is part of an organ (the bronchus), which is part of the respiratory system which is part of the organism or person.

Type of cell	Where it is found	Function	Where you can find out more
ciliated cell	lining the trachea and bronchi	move mucus upward	page 145
root hair cells	near the ends of plant roots	absorb water and mineral salts	page 96–97
xylem vessels	in stems, roots and leaves of plants	transport water and mineral salts; help in support	page 94
palisade mesophyll cells	beneath the epidermis of a leaf	photosynthesis	page 60
nerve cells	throughout the bodies of animals	transmit information	page 162
red blood cells	in the blood of mammals	transport oxygen	page 117
sperm and egg cells	in testes and ovaries	fuse together to produce a zygote	page 214

Table 2.2 Some examples of specialised cells.

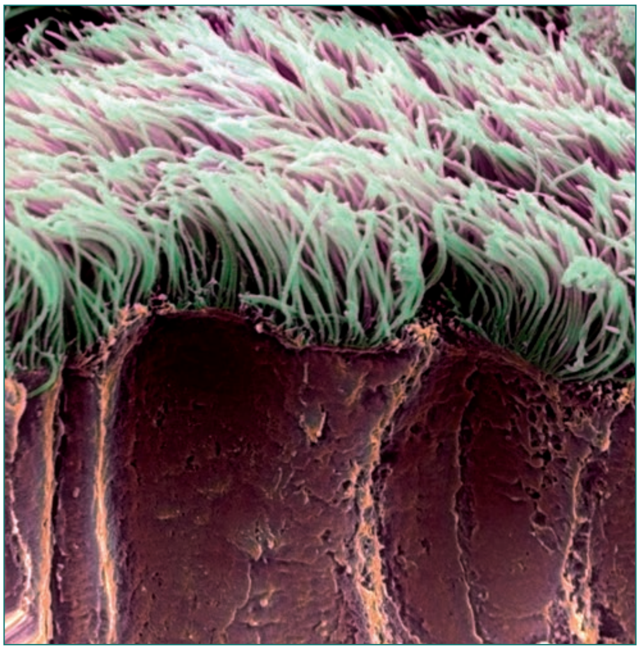


Figure 2.14 These cells make up a tissue lining the bronchus (a tube that carries air into the lungs). The tiny 'hairs' are called cilia.

Key definitions

tissue – a group of cells with similar structures, working together to perform a shared function

organ – a structure made up of a group of tissues, working together to perform specific functions

organ system – a group of organs with related functions, working together to perform body functions

Summary

You should know:

- the structure of an animal cell and a plant cell as seen using a microscope, and be able to compare them
- the functions of the different parts of animal cells and plant cells
- how cells are organised into tissues, organs and organ systems
- S how to calculate magnification using μm (micrometres).

End-of-chapter questions

1 Arrange these structures in order of size, beginning with the smallest:

stomach **mitochondrion** **starch grain** **tracheal cell** **nucleus**

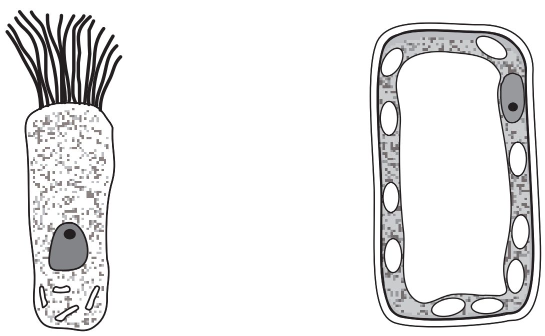
2 For each of the following, state whether it is an organelle, a cell, a tissue, an organ, an organ system, or an organism.

a heart
b trachea
c onion epidermis
d onion bulb
e onion plant
f human being
g lung

3 State which part of a plant cell:
 a makes food by photosynthesis
 b releases energy from food
 c controls what goes in and out of the cell
 d stores information about making proteins
 e contains cell sap
 f protects the outside of the cell.

4 Distinguish between each pair of terms.
 a chloroplast, chlorophyll
 b cell wall, cell membrane
 c organelle, organ

5 The diagram shows two cells.



a **i** State where, in a human, a cell of type **A** would normally be found. [1]
 ii State where, in a plant, a cell of type **B** would be found. [1]

b Use only words from the list to copy and complete the statements about cell **B**.

air	**cellulose**	**chloroplasts**	**membrane**	**mitochondria**
nucleus	**starch**	**vacuole**	**wall**	**cell sap**

Cell **B** has a thick outer layer called the cell .... This is made of .... The cytoplasm of cell **B** contains many .... that are used in the process of photosynthesis. The large permanent .... is full of .... and this helps to maintain the shape of the cell. [5]

[Cambridge IGCSE® Biology 0610/21, Question 1, May/June 2010]

3 Movement in and out of cells

In this chapter, you will find out about:

- diffusion
- osmosis
- why diffusion and osmosis are important to cells and organisms
- active transport.

Diffusion spreads a deceptive scent

Like most brightly-coloured flowers, fly orchids rely on insects to transfer their pollen from one flower to another (Figure **3.1**). The pollen contains the male gametes, so the insects help the male gametes to reach the female gametes in another flower, so that fertilisation can take place.

But insects do not perform this service out of kindness. Many flowers persuade insects to pollinate them by providing sweet nectar, or lots of spare protein-rich pollen for the insects to eat.

Not so the fly orchid. This flower uses deception to attract male digger wasps.

Female digger wasps produce a chemical whose molecules diffuse through the air for long distances. The chemical, called a pheromone, is sensed by male digger wasps, which follow it up its concentration gradient to its source. There, hopefully, they will find a female wasp with which they can mate.

Fly orchids produce a very similar chemical, which diffuses outwards from the flower. Male digger wasps sense and react to it just as they do to the pheromone of the female wasps. When they arrive at its source, they try to mate – but unfortunately for the males, this source isn't a female wasp, but an orchid flower.

As they try to mate, the wasps pick up pollen from the flower. They don't seem to learn by their mistake, but continue to visit other orchid flowers, leaving orchid pollen behind as they try to mate with them.

Figure 3.1 A male digger wasp tries to mate with a fly orchid flower.

3.1 Diffusion

Atoms, molecules and ions are always moving. The higher the temperature, the faster they move. In a solid substance the particles cannot move very far, because they are held together by attractive forces between them. In a liquid they can move more freely, knocking into one another and rebounding. In a gas they are freer still, with no attractive forces between the molecules or atoms. Molecules and ions can also move freely when they are in solution.

When they can move freely, particles tend to spread themselves out as evenly as they can (Figure 3.2). This happens with gases, solutions, and mixtures of liquids. Imagine, for example, a rotten egg in one corner of a room, giving off hydrogen sulfide gas. To begin with, there will be a very high concentration of the gas near the egg, but none in the rest of the room. However, before long the hydrogen sulfide molecules have spread throughout the air in the room. Soon, you will not be able to tell where the smell first came from – the whole room will smell of hydrogen sulfide.

The hydrogen sulfide molecules have spread out, or diffused, through the air.

Key definition

diffusion – the net movement of molecules and ions from a region of their higher concentration to a region of their lower concentration down a concentration gradient, as a result of their random movement

Diffusion and living organisms.

Living organisms obtain many of their requirements by **diffusion**. They also get rid of many of their waste products in this way. For example, plants need carbon dioxide for photosynthesis. This diffuses from the air into the leaves, through the stomata. It does this because there is a lower concentration of carbon dioxide inside the leaf, as the cells are using it up. Outside the leaf in the air, there is a higher concentration. Carbon dioxide molecules therefore diffuse into the leaf, down this concentration gradient.

Oxygen, which is a waste product of photosynthesis, diffuses out in the same way. There is a higher concentration of oxygen inside the leaf, because it is being made there. Oxygen therefore diffuses out through the stomata into the air.

Diffusion is also important in gas exchange for respiration in animals and plants (Figure 3.3). Cell membranes are freely permeable to oxygen and carbon dioxide, so these easily diffuse into and out of cells.

Some of the products of digestion are absorbed from the ileum of mammals by diffusion (page 85–86), and we have already seen that flowering plants use diffusion to attract pollinators like bees and wasps.

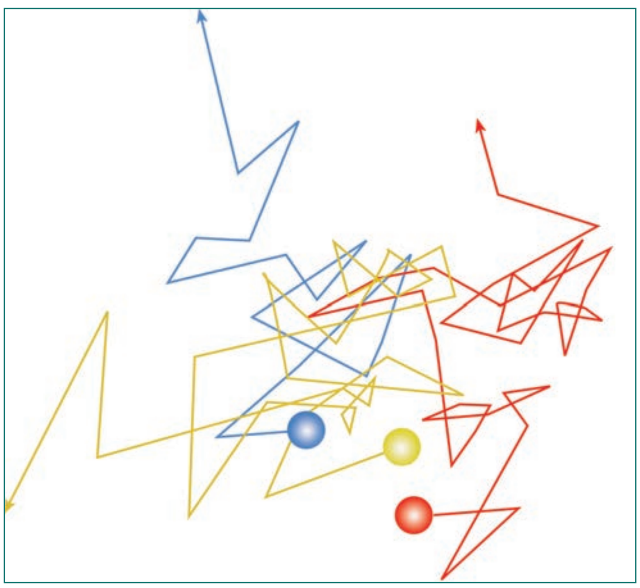


Figure 3.2 Diffusion is the result of the random movement of particles.

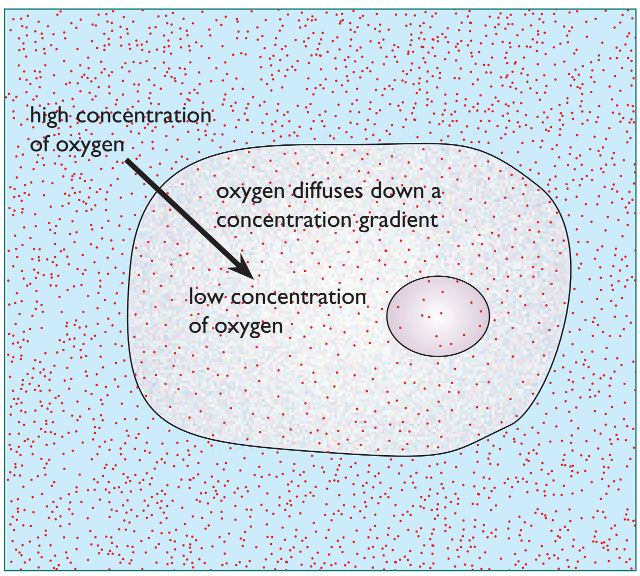


Figure 3.3 Diffusion of oxygen into a cell. The red dots represent oxygen molecules.

Questions

S 3.1 Define diffusion.

3.2 List **three** examples of diffusion in living organisms.

3.3 You will need to think about your knowledge of particle theory to answer this question.

  a What effect does an increase in temperature have on the kinetic energy of molecules of a gas or a solute?

  b Predict and explain how an increase in temperature will affect the rate of diffusion of a solute.

Activity 3.1
Demonstrating diffusion in a solution

Skill
AO3.3 Observing, measuring and recording

1 Fill a gas jar with water. Leave it for several hours to let the water become very still.
2 Carefully place a small crystal of potassium permanganate into the water.
3 Make a labelled drawing of the gas jar to show how the colour is distributed at the start of your experiment.
4 Leave the gas jar completely undisturbed for several days.
5 Make a second drawing to show how the colour is distributed.

You can try this with other coloured salts as well, such as copper sulfate or potassium dichromate.

Questions

A1 Why was it important to leave the water to become completely still before the crystal was put in?

A2 Why had the colour spread through the water at the end of your experiment?

A3 Suggest **three** things that you could have done to make the colour spread more quickly.

Activity 3.2
Investigating factors that affect the rate of diffusion S

3.2 Osmosis

Water is one of the most important compounds in living organisms. It can make up around 80% of some organisms' bodies. It has many functions, including acting as a **solvent** for many different substances. For example, substances are transported around the body dissolved in the water in blood plasma.

Every cell in an organism's body has water inside it and outside it. Various substances are dissolved in this water, and their concentrations may be different inside and outside the cell. This creates concentration gradients, down which water and solutes will diffuse, if they are able to pass through the membrane.

It's easiest to think about this if we consider a simple situation involving just one solute.

Figure **3.4** illustrates a concentrated sugar solution, separated from a dilute sugar solution by a membrane. The membrane has holes or pores in it which are very small. An example of a membrane like this is Visking tubing.

Water molecules are also very small. Each one is made of two hydrogen atoms and one oxygen atom. Sugar molecules are many times larger than this. In Visking tubing, the holes are big enough to let the water molecules through, but not the sugar molecules. Visking tubing is called a **partially permeable** membrane because it will let some molecules through but not others.

There is a higher concentration of sugar molecules on the right-hand side of the membrane in Figure **3.4**, and a lower concentration on the left-hand side. If the membrane was not there, the sugar molecules would diffuse from the concentrated solution into the dilute one until they were evenly spread out. However, they cannot do this because the pores in the membrane are too small for them to get through.

There is also a concentration gradient for the water molecules. On the left-hand side of the membrane, there is a high concentration of water molecules. On the

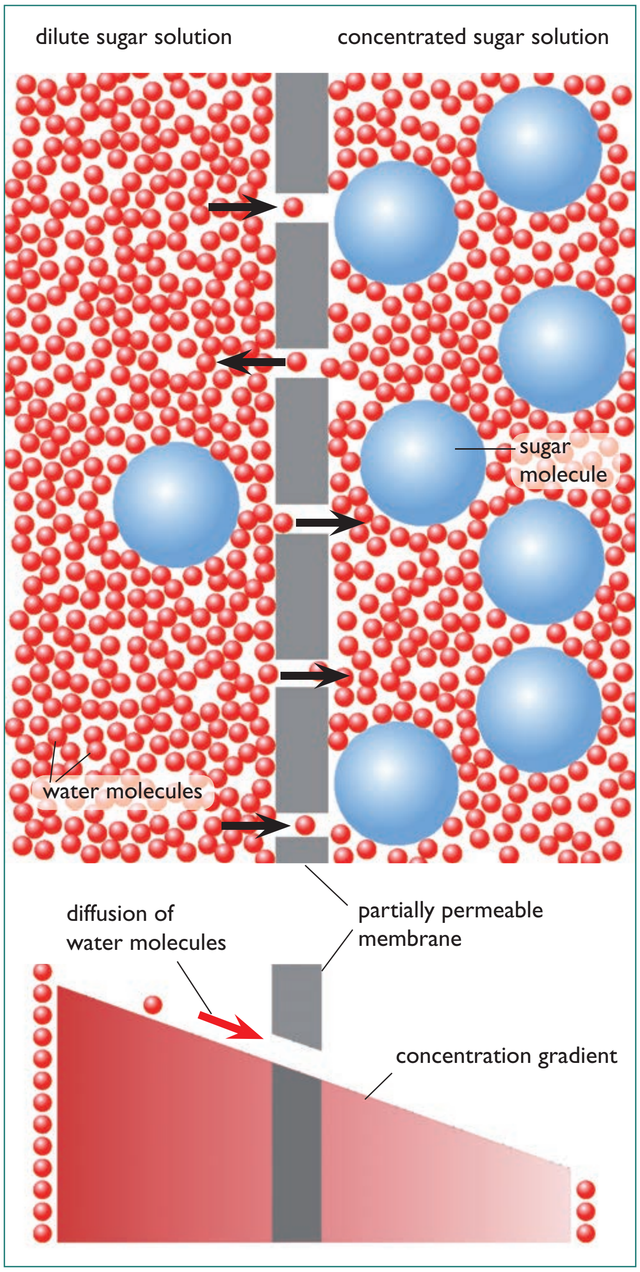


Figure 3.4 Osmosis.

right-hand side, the concentration of water molecules is lower because a lot of space is taken up by sugar molecules.

Because there are more water molecules on the left hand side, at any one moment more of them will 'hit' a hole in the membrane and move through to the other side than will go the other way (right to left). Over time, there will be an overall, or net, movement of water from left to right. This is called **osmosis**.

You can see that osmosis is really just a kind of diffusion. It is the diffusion of water molecules, in a situation where the water molecules but not the solute molecules can pass through a membrane.

S

It is actually rather confusing to talk about the 'concentration' of water molecules, because the term 'concentration' is normally used to mean the concentration of the solute dissolved in the water. It is much better to use a different term instead. We say that a dilute solution (where there is a lot of water) has a high **water potential**. A concentrated solution (where there is less water) has a low water potential.

In Figure 3.4, there is a high water potential on the left-hand side and a low water potential on the right-hand side. There is a water potential gradient between the two sides. The water molecules diffuse down this gradient, from a high water potential to a low water potential.

Questions

3.4 Which is larger – a water molecule or a sugar molecule?

3.5 What is meant by a partially permeable membrane?

3.6 Give **two** examples of partially permeable membranes.

3.7 How would you describe a solution that has a high concentration of water molecules?

Key definition

S **osmosis** – the diffusion of water molecules from a region of higher water potential (dilute solution) to a region of lower water potential (concentrated solution), through a partially permeable membrane

Cell membranes

Cell membranes behave very much like Visking tubing. They let some substances pass through them, but not others. They are partially permeable membranes.

There is always cytoplasm on one side of any cell membrane. Cytoplasm is a solution of proteins and other substances in water. There is usually a solution on the other side of the membrane, too. Inside large animals, cells are surrounded by tissue fluid (page **122**). In the soil, the roots of plants are often surrounded by a film of water.

So, cell membranes often separate two different solutions – the cytoplasm, and the solution around the cell. If the solutions are of different concentrations, then osmosis will occur.

Activity 3.3
Diffusion of substances through a membrane

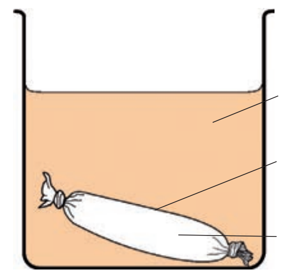
Skills

AO3.1 Using techniques, apparatus and materials
AO3.3 Observing, measuring and recording
AO3.4 Interpreting and evaluating observations and data

You are going to investigate diffusion of two different substances dissolved in water (solutes). When a substance is dissolved, its particles are free to move around.

In this investigation, you will use starch solution and iodine solution. The solutions will be separated by a membrane made out of Visking tubing. Visking tubing has microscopic holes in it. The holes are big enough to let water molecules and iodine molecules through, but not starch molecules, which are bigger than the holes.

1 Collect a piece of Visking tubing. Moisten it and rub it until it opens.
2 Tie a knot in one end of the tubing.
3 Using a pipette, carefully fill the tubing with some starch solution.
4 Tie the top of the tubing very tightly, using thread.
5 Rinse the tubing in water, just in case you got any starch on the outside of it.
6 Put some iodine solution into a beaker.
7 Gently put the Visking tubing into the iodine solution, so that it is completely covered, as shown in the diagram.
8 Leave the apparatus for about 10 minutes.



Questions

A1 What colour were the liquids inside and outside the tubing at the start of the experiment?

A2 What colour were the liquids inside and outside the tubing at the end of the investigation?

A3 When starch and iodine mix, a blue-black colour is produced. Where did the starch and iodine mix in your experiment?

A4 Did either the starch particles or the iodine particles diffuse through the Visking tubing? How can you tell?

A5 Copy and complete these sentences.

At the start of the experiment, there were starch molecules inside the tubing but none outside the tubing. Starch particles are too .... to go through Visking tubing.

At the start of the experiment, there were iodine molecules .... the tubing but none .... the tubing. The iodine molecules diffused into the tubing, down their .... gradient.

When the starch and iodine molecules mixed, a .... colour was produced.

Osmosis and animal cells

Figure **3.5** illustrates an animal cell in pure water. The cytoplasm inside the cell is a fairly concentrated solution. The proteins and many other substances dissolved in it are too large to get through the cell membrane. Water molecules, though, can get through.

If you compare this situation with Figure **3.4** (page **31**), you will see that they are similar. The dilute solution in Figure **3.4** and the pure water in Figure **3.5** are each separated from a concentrated solution by a partially permeable membrane. In Figure **3.5**, the concentrated solution is the cytoplasm and the partially permeable membrane is the cell membrane. Therefore, osmosis will occur.

Water molecules will diffuse from the dilute solution into the concentrated solution. What happens to the cell? As more and more water enters the cell, it swells. The cell membrane has to stretch as the cell gets bigger, until eventually the strain is too much, and the cell bursts.

Figure **3.6** illustrates an animal cell in a concentrated solution. If this solution is more concentrated than the cytoplasm, then water molecules will diffuse out of the cell. Look at Figure **3.4** (page **31**) to see why.

As the water molecules go out through the cell membrane, the cytoplasm shrinks. The cell shrivels up.

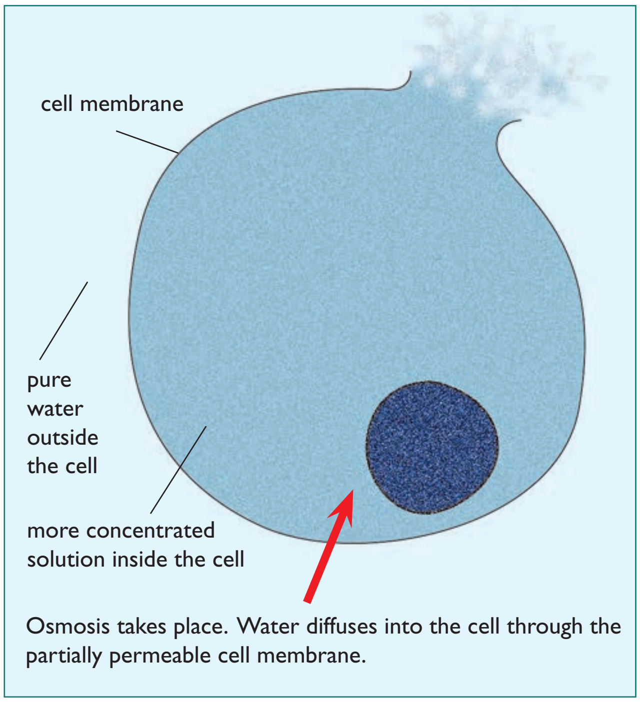


Figure 3.5 Animal cells burst in pure water.

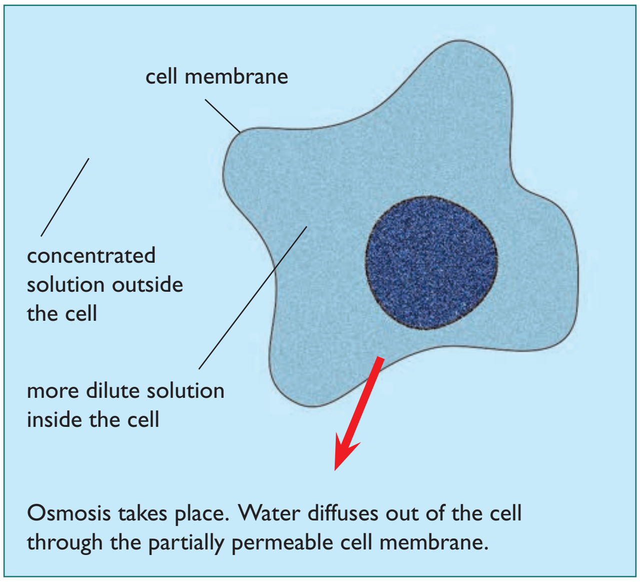


Figure 3.6 Animal cells shrink in a concentrated solution.

Osmosis and plant cells

Plant cells do not burst in pure water. Figure **3.7** illustrates a plant cell in pure water. Plant cells are surrounded by a cell wall. This is fully permeable, which means that it will let any molecules go through it.

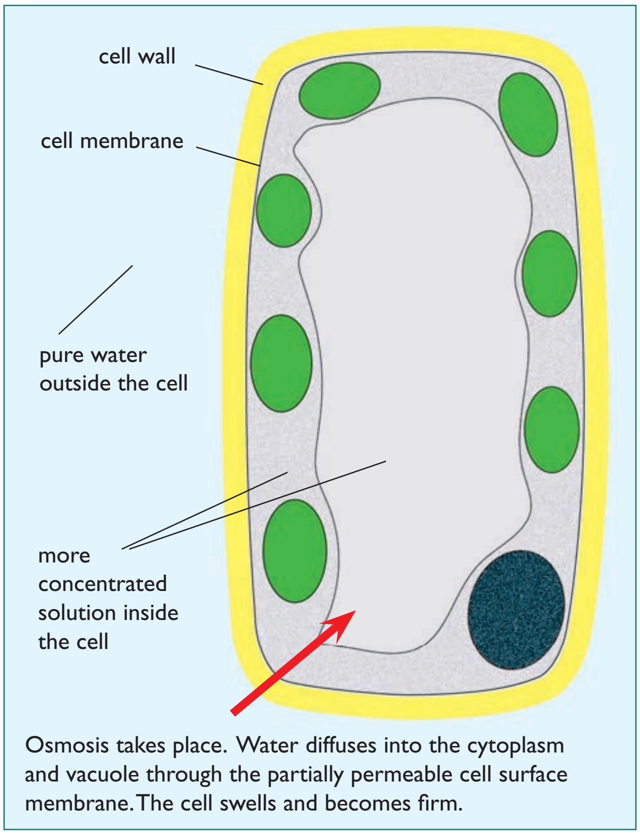


Figure 3.7 Plant cells become swollen and firm in pure water.

Although it is not easy to see, a plant cell also has a cell surface membrane just like an animal cell. The cell membrane is partially permeable. A plant cell in pure water will take in water by osmosis through its partially permeable cell membrane in the same way as an animal cell. As the water goes in, the cytoplasm and vacuole will swell.

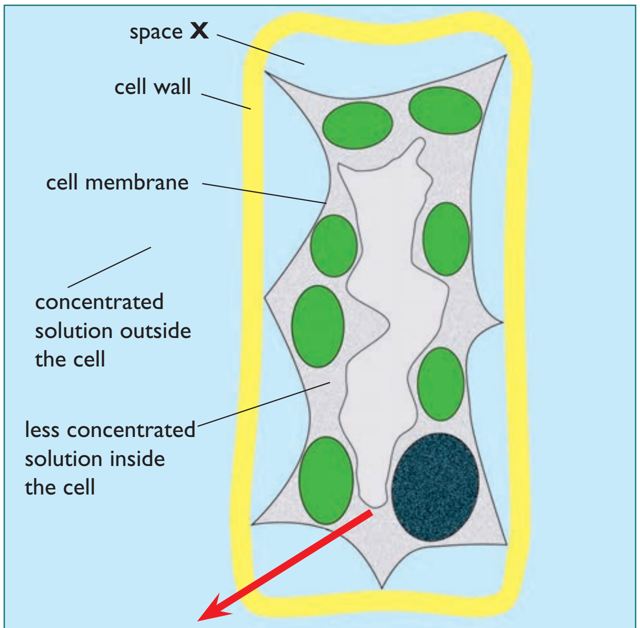
However, the plant cell has a very strong cell wall around it. The cell wall is much stronger than the cell membrane and it stops the plant cell from bursting. The cytoplasm presses out against the cell wall, but the wall resists and presses back on the contents.

A plant cell in this state is rather like a blown-up tyre – tight and firm. It is said to be **turgid**. The turgidity of its cells helps a plant that has no wood in it to stay upright, and keeps the leaves firm. Plant cells are usually turgid.

Figure **3.8** and Figure **3.9** illustrate a plant cell in a concentrated solution. Like the animal cell in Figure **3.6**, it will lose water by osmosis. The cytoplasm shrinks, and stops pushing outwards on the cell wall. Like a tyre when some of the air has leaked out, the cell becomes floppy. It is said to be **flaccid**. If the cells in a plant become flaccid, the plant loses its firmness and begins to wilt.

Figure 3.8 These onion cells have been placed in a concentrated solution. The cytoplasm has shrunk inwards, leaving big gaps between itself and the cell walls (×300).

Activity 3.4
Investigate and describe the effects on plant tissue of immersing them in different solutions



Osmosis takes place. Water diffuses out of the cytoplasm and vacuole through the partially permeable cell membrane. First, the cell shrinks slightly and becomes flaccid. Then the cell membrane pulls away from the cell wall, and the cell is plasmolysed.

Figure 3.9 Plant cells become flaccid and may plasmolyse in a concentrated solution.

If the solution is very concentrated, then a lot of water will diffuse out of the cell. The cytoplasm and vacuole go on shrinking. The cell wall, though, is too stiff to be able to shrink much. As the cytoplasm shrinks further and further into the centre of the cell, the cell wall gets left behind. The cell membrane, surrounding the cytoplasm, tears away from the cell wall.

A cell like this is said to be **plasmolysed**. This does not normally happen because plant cells are not usually surrounded by very concentrated solutions. However, you can make cells become plasmolysed if you do Activity **3.4**. Plasmolysis usually kills a plant cell because the cell membrane is damaged as it tears away from the cell wall.

Questions

3.8 What happens to an animal cell in pure water?

3.9 Explain why this does not happen to a plant cell in pure water.

3.10 Which part of a plant cell is:

a fully permeable?

b partially permeable?

Questions

3.11 What is meant by a turgid cell?
3.12 What is plasmolysis?
3.13 How can plasmolysis be brought about?
3.14 In Figure **3.9**, what fills space **X**? Explain your answer.
3.15 Describe the events shown in Figures **3.5** and **3.6** in terms of water potential.

3.3 Active transport

There are many occasions when cells need to take in substances which are only present in small quantities around them. Root hair cells in plants, for example, take in nitrate ions from the soil. Very often, the concentration of nitrate ions inside the root hair cell is higher than the concentration in the soil. The diffusion gradient for the nitrate ions is out of the root hair, and into the soil.

Despite this, the root hair cells are still able to take nitrate ions in. They do it by a process called **active transport**. Active transport is an energy-consuming process by which substances are transported against their concentration gradient. The energy is provided by respiration in the cell.

In the cell membrane of the root hair cells are special transport proteins. These proteins pick up nitrate ions from outside the cell, and then change shape in such a way that they push the nitrate ions through the cell membrane and into the cytoplasm of the cell.

As its name suggests, active transport uses energy. The energy is provided by respiration inside the root hair cells. (You can find out about respiration in Chapter **11**.) Energy is needed to produce the shape change in the transport protein. You can think of active transport as a process in which chemical energy that has been released from glucose (by respiration) is converted into kinetic energy of molecules and ions.

Most other cells can carry out active transport. In the human small intestine, for example, glucose can be actively transported from the lumen of the intestine into the cells of the villi. In kidney tubules, glucose is actively transported out of the tubule and into the blood.

Figure **3.10** shows how active transport of glucose takes place.

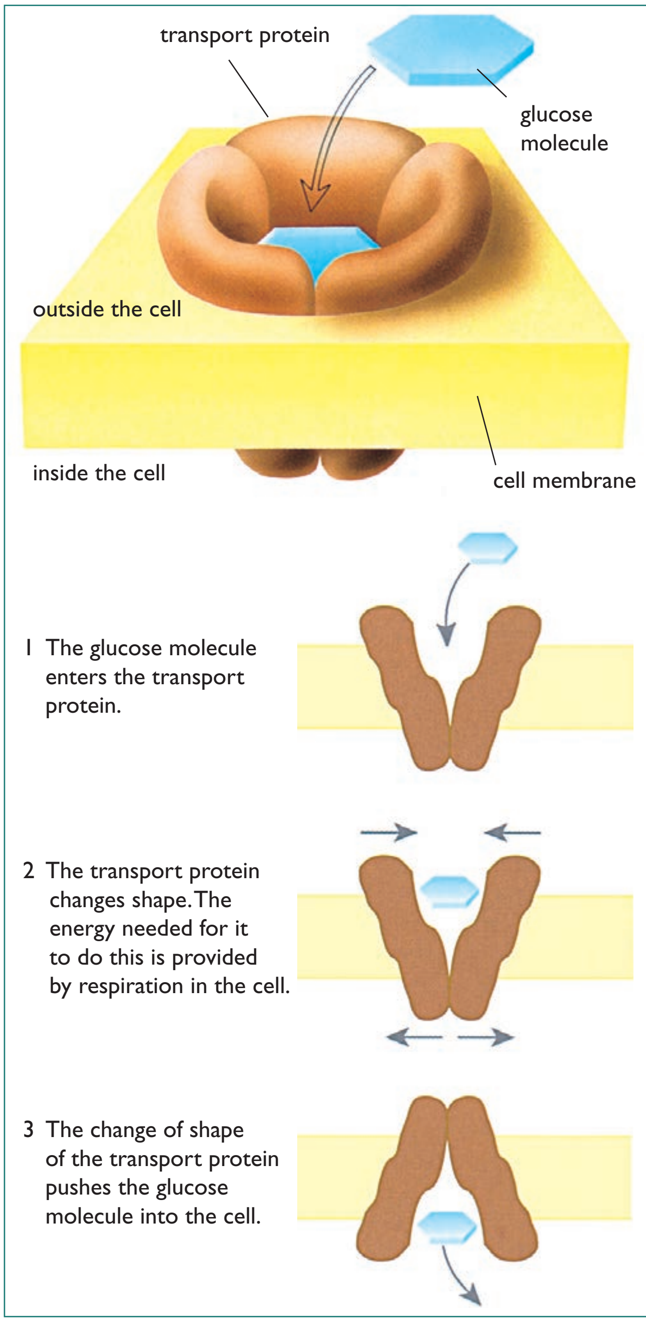


Figure 3.10 Active transport.

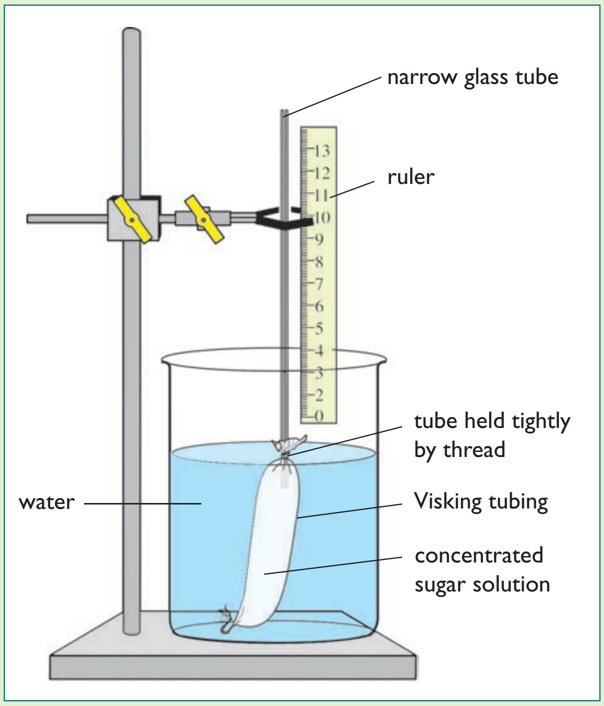
Key definition

active transport – the movement of molecules and ions in or out of a cell through the cell membrane against a concentration gradient, using energy from respiration

Activity 3.5
Measuring the rate of osmosis

Skills
A03.1 Using techniques, apparatus and materials
A03.2 Planning
A03.3 Observing, measuring and recording
A03.4 Interpreting and evaluating observations and data

1 Collect a piece of Visking tubing. Moisten it and rub it between your fingers to open it. Tie one end tightly.
2 Use a dropper pipette to put some concentrated sugar solution into the tubing.
3 Place a long, narrow glass tube into the tubing, as shown in the diagram. Tie it very, very tightly, using thread.
4 Place the tubing inside a beaker of water, as shown in the diagram.



5 Mark the level of liquid inside the glass tube.
6 Make a copy of this results chart.

Time in minutes	0	2	4	6	8	10	12	14	16
Height of liquid in mm									

Every 2 minutes, record the level of the liquid in the glass tube.
7 Collect a sheet of graph paper. Draw a line graph of your results. Put *time in minutes* on the *x*-axis, and *height in mm* on the *y*-axis.

Questions

A1 Describe what happened to the liquid level inside the glass tube.
A2 Explain why this happened.
A3 Use your graph to work out the mean (average) rate at which the liquid moved up the tube, in mm per second. (Ask your teacher for help if you are not sure how to do this.)
A4 Predict what would have happened to the rate of osmosis in this experiment if you had used a kind of Visking tubing with ridges and grooves in it, giving it a larger surface area. Explain your answer.
A5 When temperature rises, particles move more quickly. Describe how you could use this apparatus to carry out an experiment to investigate the effect of temperature on the rate of osmosis. Think about the following things.
- What will you vary in your experiment?
- What will you keep the same?
- What will you measure, when will you measure it and how will you measure it?
- How will you record and display your results?
- Predict the results that you would expect.

Activity 3.6
Osmosis and potato strips

Summary

You should know:

- how diffusion results from the random movement of particles
- the factors that affect the rate of diffusion
- why diffusion is important to cells and living organisms
- the importance of water as a solvent
- about osmosis, which is a special kind of diffusion, involving water molecules
- how osmosis affects animal cells and plant cells
- about active transport, and why it is important to cells.

End-of-chapter questions

1 Which of a–d below is an example of **i** diffusion, **ii** osmosis, or **iii** neither? Explain your answer in each case.

a Water moves from a dilute solution in the soil into the cells in a plant's roots.
b Saliva flows out of the salivary glands into your mouth.
c A spot of blue ink dropped into a glass of still water quickly colours all the water blue.
d Carbon dioxide goes into a plant's leaves when it is photosynthesising.

2 Each of these statements was made by a candidate in an examination. Each one contains at least one error. Decide what is wrong with each statement, and rewrite it correctly.

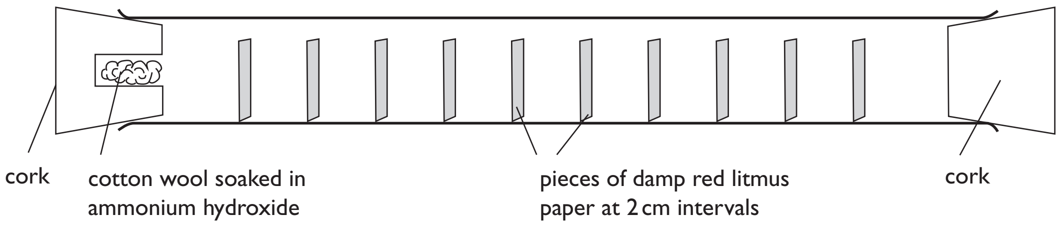
a If Visking tubing containing a sugar solution is put into a beaker of water, the sugar solution moves out of the tubing by osmosis.
b Plant cells do not burst in pure water because the cell wall stops water getting into the cell.
c When a plant cell is placed in a concentrated sugar solution, water moves out of the cell by osmosis, through the partially permeable cell wall.
S **d** Animal cells plasmolyse in a concentrated sugar solution.

3 Explain each of the following.

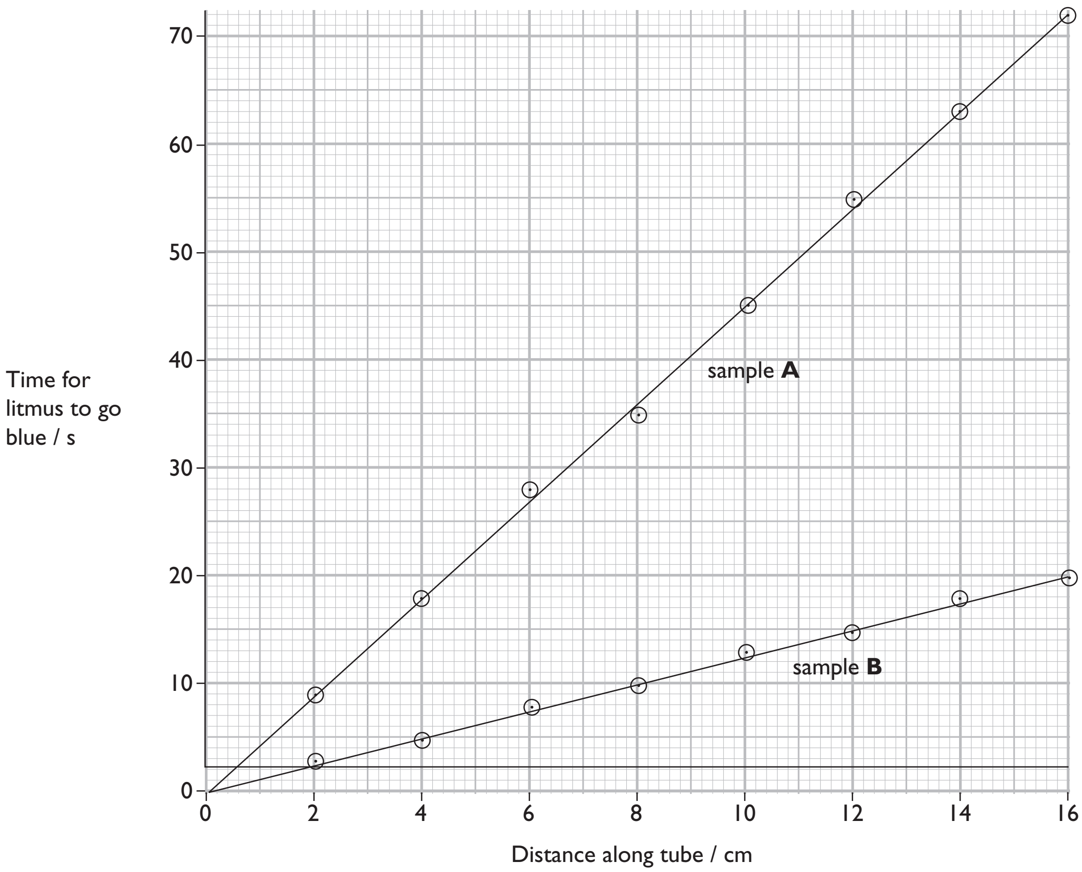
a Diffusion happens faster when the temperature rises.
b Oxygen diffuses out of a plant leaf during daylight hours.
c Water molecules can pass through Visking tubing, but starch molecules cannot.
d An animal cell bursts if placed in pure water.
e If a plant is short of water, its leaves lose their firmness and the plant wilts.

4 a Define diffusion. [2]

b The diagram below shows an apparatus that was set up to investigate diffusion.



The graph below shows the results for two samples of ammonium hydroxide that were investigated.



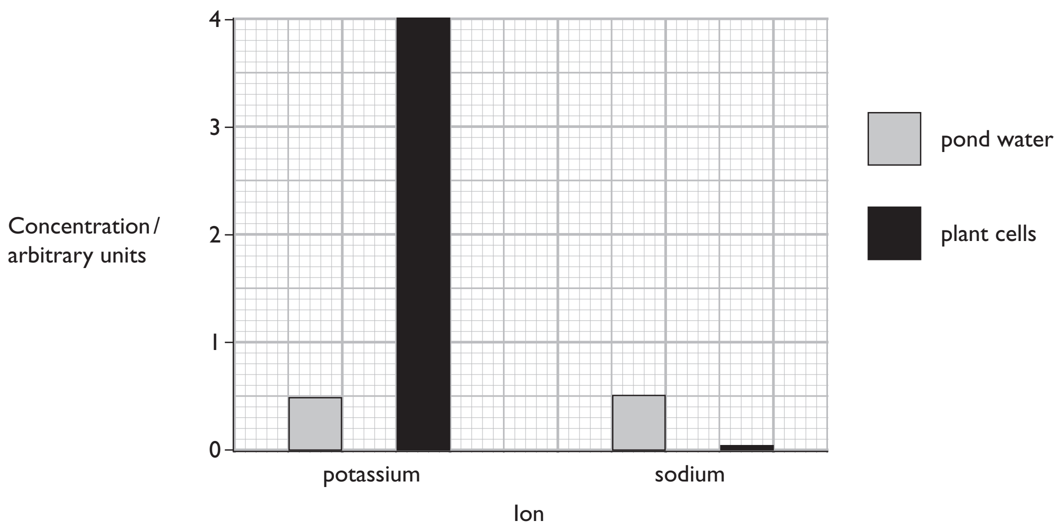
The table below gives data for a third sample, **C**, of ammonium hydroxide that was investigated.

Distance of red litmus paper along tube / cm	Time for red litmus paper to go blue / s
2	6
4	10
6	15
8	21
10	25
12	29
14	35
16	41

i Plot the data in the table on a copy of the graph. [3]
ii Suggest what has caused the litmus paper to go blue. [1]
iii State which sample of ammonium hydroxide took longest to travel 10 cm along the tube. [1]
iv What can you suggest about the concentration of sample **C**? Explain your answer. [2]

[Cambridge IGCSE® Biology 0610/2, Question 8, October/November 2004]

5 The bar chart shows the concentration of potassium ions and sodium ions in a sample of pond water, and in the cells of a plant growing in the water.



a Describe the differences between the concentrations of the ions in the pond water and in the plant cells. [3]
b Suggest the process by which the ions move beweeen the pond water and the plant cells. Explain why you think this process is involved. [2]
c Describe how the process that you have described in your answer to **b** takes place. [4]

4 The chemicals of life

In this chapter, you will find out about:

- why water is so important to living organisms
- what carbohydrates, fats (lipids) and proteins are made of, and their properties
- the roles of carbohydrates, fats and proteins in living organisms
- how to test for the presence of carbohydrates, lipids and proteins
- the structure of DNA.

Did meteorites spark the beginning of life on Earth?

On the morning of September 26th, 1969, the people of Murchison, in Australia, were surprised by a roaring noise and bright lights in the sky. Many people rushed out of their homes and offices to see what was happening. They were witnessing the fall of what is now known as the Murchison meteorite.

The meteorite broke up as it entered the Earth's atmosphere, so that when the pieces hit the ground they were spread over an area of 13 km^2. The largest fragment that was picked up had a mass of 7 kg, but it is estimated the mass of the original meteorite was probably more than 100 kg.

The meteorite was especially useful for research because people had seen it fall, so scientists knew exactly when and how it had reached the Earth. Studies of the meteorite suggest that it formed about 4.6 billion years ago – the time at which the Sun was forming.

Chemists have analysed the substances that the meteorite fragments are made of. They contain a lot of carbon. And some of this carbon is in molecules of amino acids. There are 15 different amino acids in the meteorite.

We think we understand how amino acids can form in space – for example from hydrogen, carbon monoxide and nitrogen in a hot, newly-formed asteroid as it cools. Many meteorites are known to contain amino acids. And this has made scientists wonder if perhaps these amino acids, brought to Earth from outer space, might have been important in the origin of life on Earth. In the early history of the Earth, before it had developed an atmosphere, many more meteorites hit the surface than happens today, and they could have brought quite large quantities of amino acids to our planet.

Today, all living organisms contain 20 different amino acids, which are used to build proteins. It's intriguing to think that perhaps life would not have evolved without these deliveries from outer space (Figure **4.1**).

Figure 4.1 A huge meteor fell near Chelyabinsk in Russia in February 2013, producing a shock wave that shattered windows and injured more than 1500 people. This photo was taken from a car dashboard video camera.

4.1 What are you made of?

The bodies of all living things are made of many different kinds of chemicals. Most of our bodies are made up of water. We also contain carbohydrates, proteins and fats. These substances are what our cells are made of. Each of them is vital for life.

In this chapter, we will look at each of these kinds of substances in turn. As you work through your biology course, you will keep meeting them over and over again.

It will help if you have a basic understanding of the meanings of the terms atom, element and molecule. If you are not sure about these, ask your biology or chemistry teacher to explain them to you.

Water

In most organisms, almost 80% of the body is made up of water. We have seen that cytoplasm is a solution of many different substances in water. The spaces between our cells are also filled with a watery liquid.

Inside every living organism, chemical reactions are going on all the time. These reactions are called metabolism. **Metabolic reactions** can only take place if the chemicals which are reacting are dissolved in water. Water is an important **solvent**. This is one reason why water is so important to living organisms. If their cells dry out, the reactions stop, and the organism dies.

S Water is also needed for other reasons. For example, plasma, the liquid part of blood, contains a lot of water, so that substances like glucose can dissolve in it. These dissolved substances are transported around the body. Water is also need to dissolve enzymes and nutrients in the alimentary canal, so that digestion can take place.

We also need water to help us to get rid of waste products. As you will see in Chapter **12**, the kidneys remove the waste product, urea, from the body. The urea is dissolved in water, forming urine.

Study tip

When asked why water is important to organisms, many students answer 'so that they do not dry out'. This is not a good answer – make sure you explain *why* the water is needed.

4.2 Carbohydrates

Carbohydrates include starches and sugars. Their molecules contain three kinds of atom – carbon (C), hydrogen (H), and oxygen (O). A carbohydrate molecule has about twice as many hydrogen atoms as carbon or oxygen atoms.

Sugars

The simplest kinds of carbohydrates are the **simple sugars** or **monosaccharides**. Glucose is a simple sugar. A glucose molecule is made of six carbon atoms joined in a ring, with the hydrogen and oxygen atoms pointing out from and into the ring (Figure **4.2**).

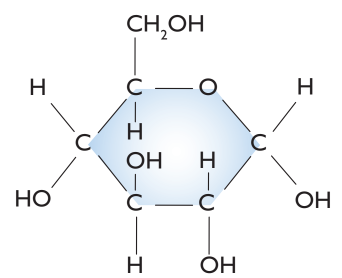


Figure 4.2 The structure of a glucose molecule.

A glucose molecule contains six carbon atoms, twelve hydrogen atoms, and six oxygen atoms. To show this, its molecular formula can be written $C_6H_{12}O_6$. This formula stands for one molecule of this simple sugar, and tells you which atoms it contains, and how many of each kind.

Although they contain many atoms, simple sugar molecules are very small (Figure **4.3**). They are soluble in water, and they taste sweet.

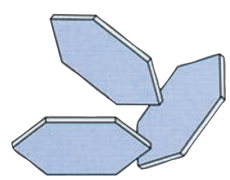


Figure 4.3 Simple sugars, or monosaccharides, have small molecules and are soluble.

If two simple sugar molecules join together, a larger molecule called a complex sugar or **disaccharide** is made (Figure **4.4**). Two examples of complex sugars are **sucrose** (the sugar we use in hot drinks, or on breakfast cereal, for example) and **maltose** (malt sugar). Like simple sugars, they are soluble in water and taste sweet.

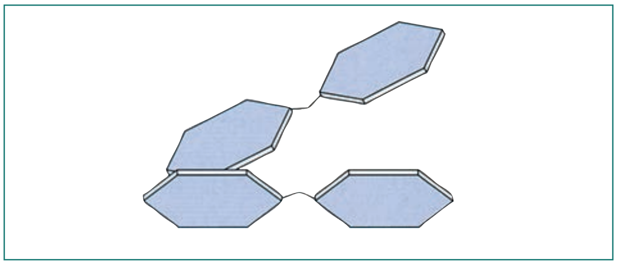


Figure 4.4 Complex sugars (disaccharides), such as maltose, are made from two simple sugars that have been joined together.

Polysaccharides

If many simple sugars join together, a very large molecule called a **polysaccharide** is made. Some polysaccharide molecules contain thousands of sugar molecules joined together in a long chain. The **cellulose** of plant cell walls is a polysaccharide and so is **starch**, which is often found inside plant cells (Figure **4.5**). Animal cells often contain a polysaccharide called **glycogen**. Most polysaccharides are insoluble, and they do not taste sweet.

Functions of carbohydrates

Carbohydrates are needed for energy. One gram of carbohydrate releases 17 kJ (kilojoules) of energy. The energy is released by respiration (Chapter **11**).

The carbohydrate that is normally used in respiration is glucose. This is also the form in which carbohydrate is transported around an animal's body. Human blood plasma contains dissolved glucose, being transported to all the cells. The cells then use the glucose to release the energy that they need to carry out the processes of life.

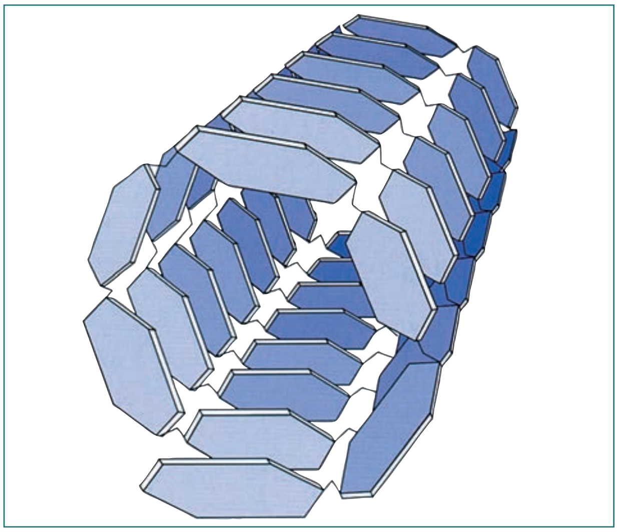


Figure 4.5 This is just a small part of a molecule of a polysaccharide, like starch.

Plants also use glucose in respiration, to provide them with energy. However, they do not transport glucose around their bodies. Instead, they transport sucrose. The cells change the sucrose to glucose when they need to use it.

Plants store carbohydrates as starch. It is quick and easy to change glucose into starch, or starch into glucose. Some plants store large quantities of starch in their seeds or tubers, and we use these as food.

Animals do not store starch. Instead, they store carbohydrates in the form of the polysaccharide glycogen. However, only small quantities of glycogen can be stored. It is mostly stored in the cells in the liver and the muscles.

The polysaccharide cellulose is used to make the criss-crossing fibres from which plant cell walls are constructed. Cellulose fibres are very strong, so the cell wall helps to maintain the shape of the plant cell.

Testing for carbohydrates

We can test for the presence of sugars by adding Benedict's solution to a food, and heating it. If the food contains **reducing sugar** (such as glucose or maltose), then a brick-red colour will be produced. The mixture changes gradually from blue, through green, yellow and orange, and finally brick red (Figure **4.6**). If there is no reducing sugar, then the Benedict's solution remains blue.

Figure 4.6 Positive results of the Benedict's test. The tube on the left contained a small amount of reducing sugar, and the one on the right a larger amount.

Activity 4.1
Testing foods for sugars

Skills

AO3.1 Using techniques, apparatus and materials
AO3.3 Observing, measuring and recording

⚠ Wear eye protection if available.
If possible, heat the tubes using a water bath. If you have to heat directly over a Bunsen flame, use a test-tube holder and point the opening of the tube away from people.
Take care if using a sharp blade to cut the food.

All simple sugars, and some complex sugars such as maltose, are **reducing sugars**. This means that they will react with a blue liquid called Benedict's solution. We can use this reaction to find out if a food or other substance contains a reducing sugar.

1 Draw a results chart.

Food	Colour with Benedict's solution	Simple sugar present

2 Cut or grind a little of the food into very small pieces. Put these into a test tube. Add some water, and shake it up to try to dissolve it.

3 Add some Benedict's solution. Benedict's solution is blue, because it contains copper salts.

4 Heat the tube to about 80 °C, in a water bath. If there is reducing sugar in the food, a brick-red precipitate will form.

5 Record your result in your results chart. If the Benedict's solution does not change colour, do not write 'no change'. Write down the actual colour that you see – for example, blue. Then write down your conclusion from the result of the test.

This test works because the reducing sugar reduces the blue copper salts to a red compound.

The test for starch is easier, as it does not involve heating. You simply add iodine solution to a sample of the food. If there is starch present, a blue-black colour is obtained (Figure 4.7). If there is no starch, the iodine solution remains orange-brown.

Figure 4.7 The black colour shows that the potato contains starch.

Activity 4.2
Testing foods for starch

Skills

AO3.1 Using techniques, apparatus and materials
AO3.3 Observing, measuring and recording

There is no need to dissolve the food for this test.

1 Draw a results chart.

2 Put a small piece of the food onto a white tile.

3 Add a drop or two of iodine solution. Iodine solution is brown, but it turns blue-black if there is starch in the food. Record each of your results and conclusions.

Question

A1 How could you test a solution to see if it contained iodine?

Questions

4.1 What is metabolism?

4.2 Why do organisms die if they do not have enough water?

4.3 Which **three** elements are contained in all carbohydrates?

4.4 The molecular formula for glucose is $C_6H_{12}O_6$. What does this tell you about a glucose molecule?

4.5 To which group of carbohydrates does each of these substances belong: **a** glucose, **b** starch and **c** glycogen?

4.6 In what form:

- **a** do most organisms use carbohydrates in respiration?
- **b** do animals transport carbohydrates in their blood?
- **c** do animals store carbohydrates in their cells?
- **d** do plants transport carbohydrates round their bodies?
- **e** do plants store carbohydrates in their cells?

4.3 Fats

Fats are also known as **lipids**. Like carbohydrates, fats contain only three kinds of atom – carbon, hydrogen and oxygen. A fat molecule is made of four smaller molecules joined together. One of these is glycerol. Attached to the glycerol are three long molecules called fatty acids (Figure **4.8**).

Fats are insoluble in water. Fats that are liquid at room temperature are called oils.

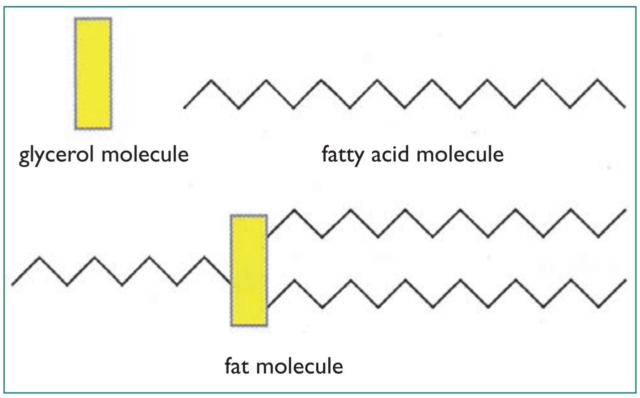


Figure 4.8 The structure of a fat molecule.

Functions of fats

Like carbohydrates, fats and oils can be used in a cell to release energy. A gram of fat gives about 39 kJ of energy. This is more than twice as much energy as that released by a gram of carbohydrate. However, most cells use carbohydrates first when they need energy, and only use fats when all the available carbohydrates have been used.

The extra energy that fats contain makes them very useful for storing energy. In mammals, some cells, particularly ones underneath the skin, become filled with large drops of fats or oils. These stores can be used to release energy when needed. This layer of cells is called **adipose tissue**. Adipose tissue also helps to keep heat inside the body – that is, it insulates the body. Animals such as walruses, which live in very cold places, often have especially thick layers of adipose tissue, called blubber (Figure **4.9**). Many plants store oils in their seeds – for example, peanut, coconut and castor oil. The oils provide a good store of energy for germination.

Figure 4.9 A walrus on the Arctic island, Spitzbergen.

Testing for fats and oils

There are several different tests for fats. One of the best is the ethanol emulsion test.

Firstly, you chop the food and shake it up with ethanol. Although fats will not dissolve in water, they do dissolve in ethanol. Next, you pour the ethanol into water. If there was any fat in the food, then the fat–ethanol mixture breaks up into millions of tiny droplets when it is mixed with the water. This mixture is called an emulsion. It looks white and opaque, like milk (Figure **4.10**). If there was no fat in the food, the mixture of water and ethanol remains transparent.

Activity 4.3
Testing foods for fats

Skills

A03.1 Using techniques, apparatus and materials
A03.3 Observing, measuring and recording

1 Draw a results chart.
2 Chop or grind a small amount of food, and put some into a very clean, dry test tube. Add some absolute (pure) ethanol. Shake it thoroughly.
3 Put some distilled water in another tube.
4 Pour some of the liquid part, but not any solid, from the first tube into the water. A milky appearance shows that there is fat in the food.

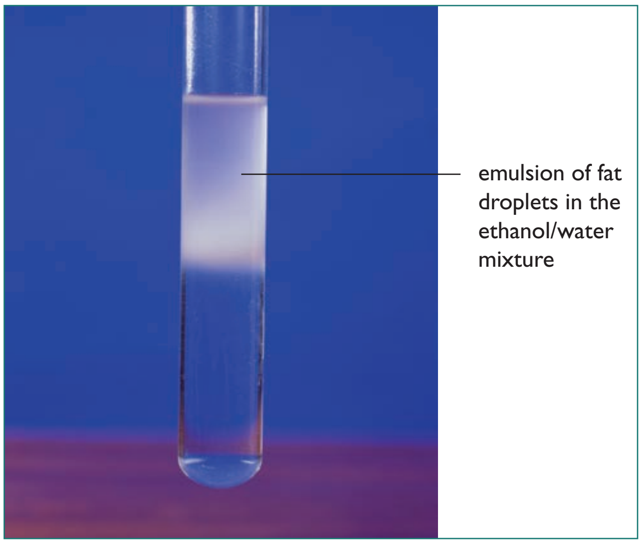


Figure 4.10 A positive result for the emulsion test.

Questions

4.7 Which **three** elements are found in all fats and oils?
4.8 State **two** uses of fats to living organisms.
4.9 We get cooking oil mostly from the seeds of plants. Why do plant seeds contain oil?

4.4 Proteins

Protein molecules contain some kinds of atoms which carbohydrates and fats do not (Figure **4.11**). As well as carbon, hydrogen and oxygen, they also contain nitrogen (N) and small amounts of sulfur (S).

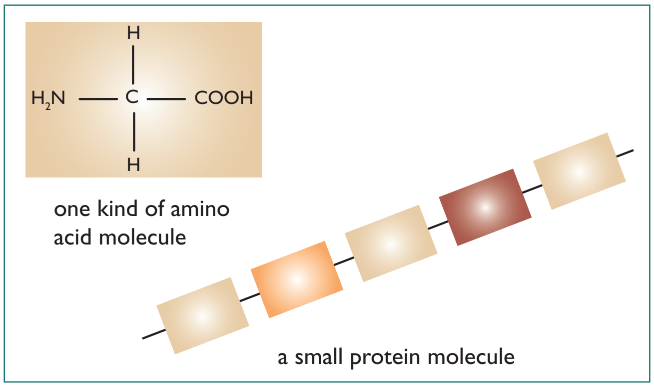


Figure 4.11 Structure of a protein molecule.

Like polysaccharides, protein molecules are made of long chains of smaller molecules joined end to end. These smaller molecules are called **amino acids**. There are about 20 different kinds of amino acid. Any of these 20 can be joined together in any order to make a protein molecule. Each protein is made of molecules with amino acids in a precise order. Even a small difference in the order of amino acids makes a different protein, so there are millions of different proteins which could be made.

Functions of proteins

Some proteins are soluble in water; an example is haemoglobin, the red pigment in blood. Others are insoluble in water; for example, keratin. Hair and fingernails are made of keratin.

Unlike carbohydrates, proteins are not normally used to provide energy. Many of the proteins in the food you eat are used for making new cells. New cells are needed for growing, and for repairing damaged parts of the body. In particular, cell membranes and cytoplasm contain a lot of protein.

Proteins are also needed to make antibodies. These help to kill bacteria and viruses inside the body. Enzymes are also proteins.

S

The long chains of amino acids from which protein molecules are formed can curl up into different shapes. The way in which the chain curls up, and therefore the three-dimensional shape of the protein molecule, is determined by the sequence of amino acids in the chain. Different sequences of amino acids result in different shapes of protein molecules.

For most protein molecules, their shape directly affects their function. For example, as you will see in Chapter **5**, some protein molecules, called enzymes, act as catalysts. The shape of the enzyme molecule determines which reactions it can catalyse (Figure **4.12**).

Similarly, the shape of an antibody molecule determines the kinds of bacteria or viruses that it can attach to. Different shapes of antibody molecules are needed to bind to different kinds of bacteria and viruses. Each different kind of antibody therefore has a different sequence of amino acids from which it is built.

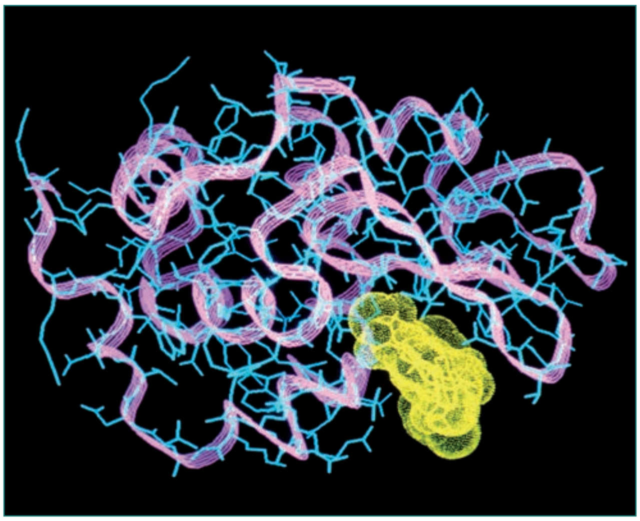


Figure 4.12 This is a model of an enzyme called lysozyme, which is found in saliva and tears. The purple band represents the chain of amino acids, which is coiled up to produce a small depression called the active site. The yellow part is another molecule, the substrate, that fits perfectly into the active site.

Questions

4.10 Name **two** elements found in proteins that are not found in carbohydrates.

4.11 How many different amino acids are there?

4.12 In what way are protein molecules similar to polysaccharides?

4.13 Give **two** examples of proteins.

4.14 State **three** functions of proteins in living organisms.

Testing for proteins

The test for proteins is called the **biuret test** (Figure **4.13**). This involves mixing the food in water, and then adding dilute copper sulfate solution. Then dilute potassium hydroxide solution is gently added. A purple colour indicates that protein is present. If there is no protein, the mixture stays blue.

Activity 4.4
Testing foods for protein

Skills
A03.1 Using techniques, apparatus and materials
A03.3 Observing, measuring and recording

⚠ Wear eye protection if available. Potassium hydroxide is a strong alkali. If you get it on your skin, wash with plenty of cold water. Take care if using a sharp blade to cut the food.

The biuret test

The biuret test uses potassium hydroxide solution and copper sulfate solution. You can also use a ready-mixed reagent called biuret reagent, which contains these two substances already mixed together.

1. Draw a results chart.
2. Put the food into a test tube, and add a little water.
3. Add some potassium hydroxide solution.
4. Add two drops of copper sulfate solution.
5. Shake the tube gently. If a purple colour appears, then protein is present.

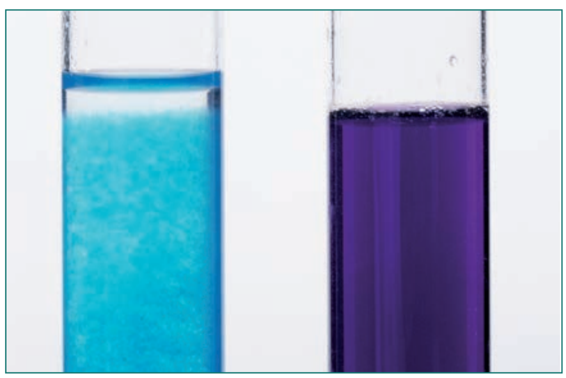


Figure 4.13 The tube on the left shows a negative result for the biuret test. The tube on the right shows a positive result.

Table **4.1** compares some properties of carbohydrates, fats and proteins.

	Carbohydrates	Fats	Proteins
Elements they contain	C, H, O	C, H, O	C, H, O, N
Smaller molecules of which they are made	simple sugars (monosaccharides)	fatty acids and glycerol	amino acids
Solubility in water	sugars are soluble; polysaccharides are insoluble	insoluble	some are soluble and some are insoluble
Why organisms need them	easily available energy (17 kJ/g)	storage of energy (39 kJ/g); insulation; making cell membranes	making cells, antibodies, enzymes, haemoglobin; also used for energy

Table 4.1 A comparison of carbohydrates, fats and proteins.

S

4.5 DNA

DNA stands for deoxyribonucleic acid. DNA is the chemical that makes up our genes and chromosomes. It is the material that we inherit from our parents, which gives us many of our characteristics.

Figure **4.14** shows the structure of a very small part of a DNA molecule. It is made of two long strands, each with a series of bases arranged along it. The bases on the two strands are held together by bonds, forming cross links. The two strands then twist together into a kind of spiral called a helix.

There are four kinds of bases, known by the letters A, C, G and T. If you look carefully at Figure **4.14**, you will see that T and A always link up with each other, and also C and G. The bases always pair up in this way.

The sequence of the bases in our DNA provides a code that is used to determine the kinds of proteins that are made in our cells. This, in turn, determines how our cells, tissues and organs develop. The sequence determines that you are a human and not a tree, as well as many of your personal characteristics such as your hair colour and your blood group. In Chapter **18**, you will find out more about how DNA does this.

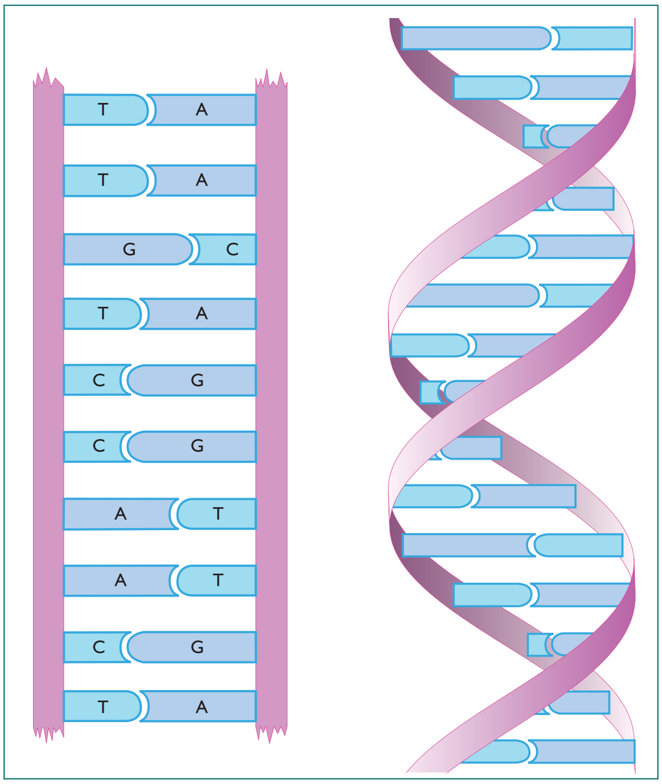


Figure 4.14 Part of a DNA molecule.

Summary

You should know:

- the functions of water in living organisms
- the structure and uses of carbohydrates, and the Benedict's test and iodine test to identify them
- the structure and uses of fats, and the ethanol emulsion test
- the structure and uses of proteins, and the biuret test
- S the relationship between the amino acid sequence, structure and function of a protein
- the structure of DNA and the importance of its base sequence.

End-of-chapter questions

1 For each of these carbohydrates, state: **i** whether it is a monosaccharide, disaccharide or polysaccharide; **ii** whether it is found in plants only, animals only or in both plants and animals; **iii** one function.

a glucose
b starch
c cellulose
d glycogen

2 Name:

a an element found in proteins but not in carbohydrates or lipids
b the small molecules that are linked together to form a protein molecule
c the reagent used for testing for reducing sugars
d the substance which the emulsion test detects
e the form in which carbohydrate is transported in a plant
f the term that describes all the chemical reactions taking place in an organism.

3 Imagine that you have been given two colourless solutions.

Describe how you could find out which of them contains the greater concentration of reducing sugar. You will need to think carefully about all the different variables that you would need to keep constant.

4 Copy and complete the table below. Do not write anything in the box that is shaded grey.

Substance	Carbohydrate, fat or protein?	Elements it contains	How to test for it	One function
haemoglobin				
glucose				
cellulose				
starch				
enzyme				

[5]

S 5 A sample of DNA was tested to find out which bases were present.
It was found that 30% of the bases in the DNA were T.

a What percentage of the bases in the DNA would you expect to be A? Explain your answer. [2]
b What percentage of the bases in the DNA would you expect to be C? Explain your answer. [2]
c Explain why two organisms that have different sequences of bases in their DNA may look different from each other. [2]

5 Enzymes

In this chapter, you will find out about:

- enzymes and what they do
- how enzymes are affected by temperature and pH
- S why enzymes are affected by temperature and pH
- how to investigate the effects of temperature and pH on enzyme activity
- how to plan, carry out and evaluate your own experiments on enzyme activity.

Forensics and salivary amylase

Forensic science is the use of scientific techniques to obtain evidence relating to crimes (Figure **5.1**).

Human saliva contains an enzyme, called salivary amylase, that helps to digest starch in the mouth. Forensic scientists can test surfaces for the presence of human salivary amylase. This can help to determine whether a person was present at the scene of a crime.

When the test first came in, it was only able to detect the activity of amylase – that is, whether starch was digested. Although this could be useful, a positive result did not prove that a person had left saliva at the scene. This is because amylase is also produced by many other organisms, such as bacteria and fungi.

In the late 1980s, a new test that could detect human amylase directly was introduced. However, this test can still give positive results for amylase from other organisms, including rats and gorillas. Although it is very unlikely that a gorilla was present at the scene of a crime, it is often possible that a rat might have left the saliva behind.

Today, forensic scientists are also able to search for cheek cells within a saliva sample. If they can find any, then they can test the DNA in them. This can then provide evidence that can link a particular person to the crime scene.

Figure 5.1 Forensic scientists at a crime scene. Can you suggest why they are wearing clothing that covers most of the their bodies?

5.1 Biological catalysts

Many chemical reactions can be speeded up by substances called **catalysts**. A catalyst alters the rate of a chemical reaction, without being changed itself.

Within any living organism, chemical reactions take place all the time. They are sometimes called **metabolic reactions**. Almost every metabolic reaction is controlled by catalysts called **enzymes**. Without enzymes, the reactions would take place very slowly, or not at all. Enzymes ensure that the rates of metabolic reactions are great enough to sustain life.

Key definitions

catalyst – a substance that increases the rate of a chemical reaction and is not changed by the reaction

enzymes – proteins that function as biological catalysts

For example, inside the alimentary canal, large molecules are broken down to smaller ones in the process of digestion. These reactions are speeded up by enzymes. A different enzyme is needed for each kind of food. For example, starch is digested to the sugar maltose by an enzyme called **amylase**. Protein is digested to amino acids by **protease**.

These enzymes are also found in plants – for example, in germinating seeds, where they digest the food stores for the growing seedling. Many seeds contain stores of starch. As the seed soaks up water, the amylase is activated and breaks down the starch to maltose. The maltose is soluble, and is transported to the embryo in the seed. The embryo uses it to provide energy for growth, and also to provide glucose molecules that can be strung together to make cellulose molecules, for the cell walls of the new cells produced as it grows.

Another enzyme which speeds up the breakdown of a substance is **catalase**. Catalase works inside the cells of living organisms – both animals and plants – for example, in liver cells or potato cells. It breaks down hydrogen peroxide to water and oxygen. This is necessary because hydrogen peroxide is produced by many of the chemical reactions which take place inside cells. Hydrogen peroxide is a very dangerous substance, and must be broken down immediately.

Not all enzymes help to break things down. Many enzymes help to make large molecules from small ones. One example of this kind of enzyme is starch phosphorylase, which builds starch molecules from glucose molecules inside plant cells.

Naming enzymes

Enzymes are named according to the reaction that they catalyse. For example, enzymes which catalyse the breakdown of carbohydrates are called **carbohydrases**. If they break down proteins, they are **proteases**. If they break down fats (lipids) they are **lipases**.

Sometimes, they are given more specific names than this. For example, we have seen that the carbohydrase that breaks down starch is called **amylase**. One that breaks down maltose is called **maltase**. One that breaks down sucrose is called **sucrase**.

The lock and key mechanism

An enzyme works by allowing the molecule of the substance on which it is acting to fit into it. The fit has to be perfect. The enzyme is like a lock, into which another molecule fits like a key. We say that the shape of the enzyme and the shape of the substrate are complementary to one another. Figure **5.2** shows how this works.

The active site

S

A chemical reaction always involves one substance changing into another. In an enzyme-controlled reaction, the substance which is present at the beginning of the reaction is called the **substrate**. The substance which is made by the reaction is called the **product**.

For example, in saliva there is an enzyme called amylase. It catalyses the breakdown of starch to the complex sugar maltose. In this reaction, starch is the substrate, and maltose is the product.

$$\text{starch} \xrightarrow{\text{amylase}} \text{maltose}$$

Figure **5.3** shows how amylase does this. An amylase molecule has a dent in it called its **active site**. This has a shape that is complementary to the shape of part of a starch molecule. When the starch molecule is in the active site, the enzyme breaks it apart.

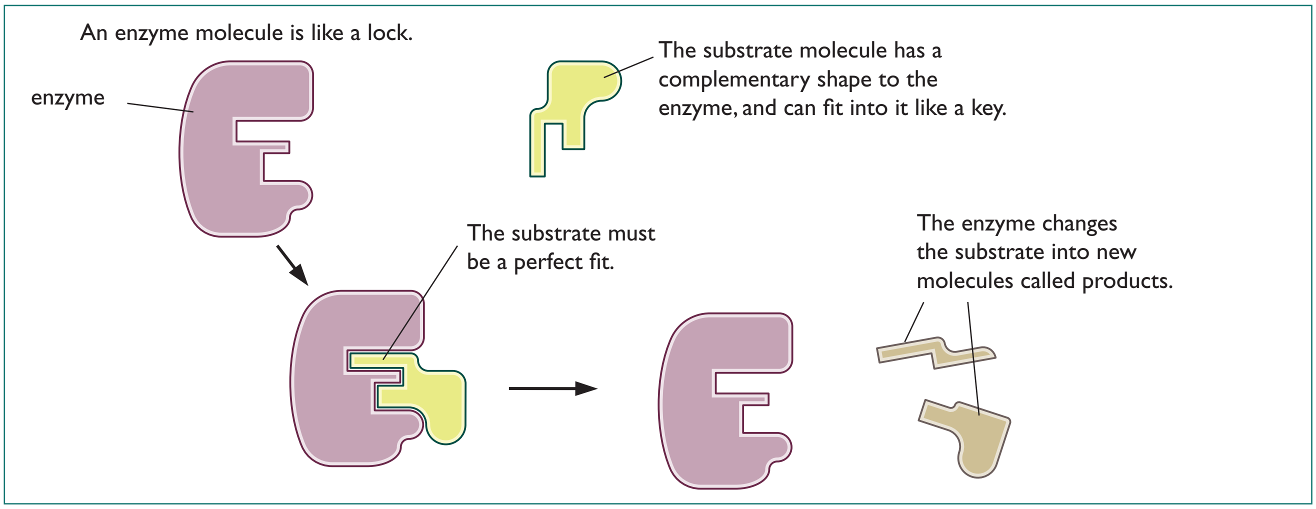


Figure 5.2 The lock and key mechanism.

All enzymes have active sites. Each enzyme has an active site that exactly fits its substrate. This means that each enzyme can only act on a particular kind of substrate. Amylase, for example, cannot break down protein molecules, because they do not fit into its active site.

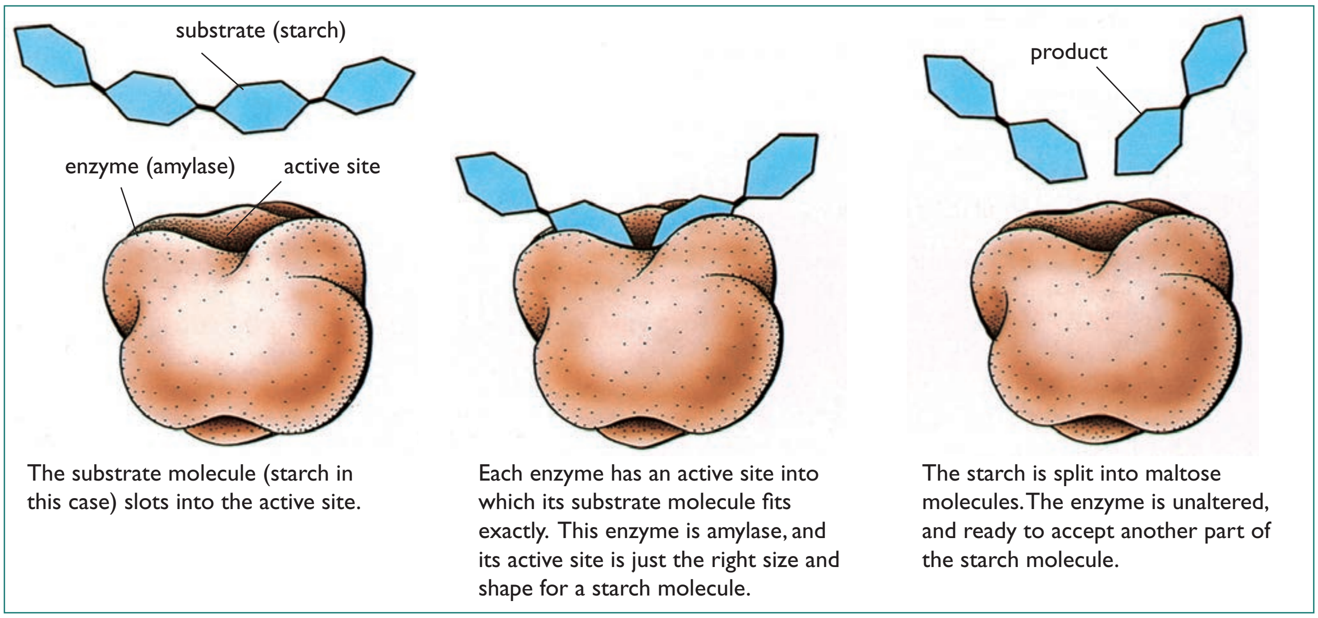


Figure 5.3 How an enzyme works.

Questions

5.1 What is a catalyst?

5.2 What are the catalysts inside a living organism called?

5.3 Which kinds of reaction inside a living organism are controlled by enzymes?

5.4 What is meant by a carbohydrase?

5.5 Give **one** example of a carbohydrase.

5.6 Name the substrate and product of a reaction involving a carbohydrase.

5.2 Properties of enzymes

1 **All enzymes are proteins** This may seem rather odd, because some enzymes actually digest proteins.

2 **Enzymes are made inactive by high temperature** This is because they are protein molecules, which are damaged by heat.

3 **Enzymes work best at a particular temperature** Enzymes which are found in the human body usually work best at about 37 °C (Figure **5.4**).

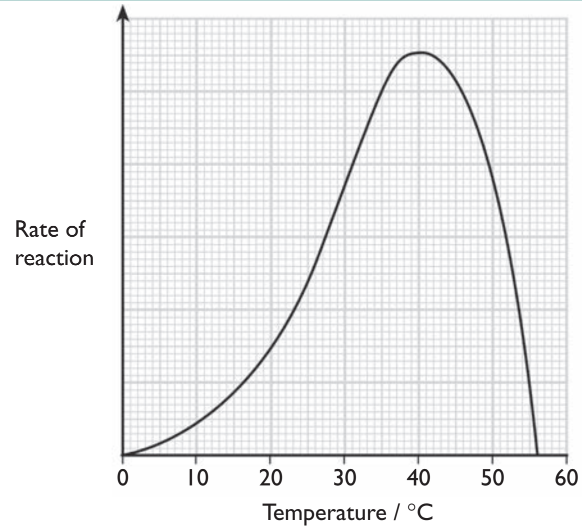


Figure 5.4 How temperature affects enzyme activity.

4 **Enzymes work best at a particular pH** pH is a measure of how acid or alkaline a solution is. Some enzymes work best in acid conditions (low pH). Others work best in neutral or alkaline conditions (high pH) (Figure **5.5**).

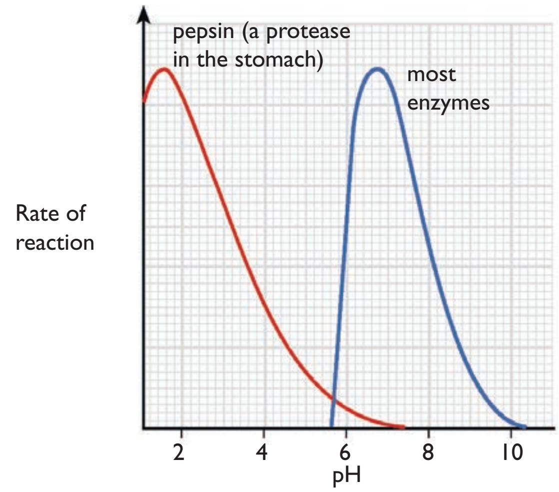


Figure 5.5 How pH affects enzyme activity.

5 **Enzymes are catalysts** They are not changed in the chemical reactions which they control. They can be used over and over again, so a small amount of enzyme can change a lot of substrate into product.

6 **Enzymes are specific** This means that each kind of enzyme will only catalyse one kind of chemical reaction.

Activity 5.1
The effect of catalase on hydrogen peroxide

Skills
AO3.1 Using techniques, apparatus and materials
AO3.3 Observing, measuring and recording
AO3.4 Interpreting and evaluating observations and data

⚠ Wear eye protection if available. Hydrogen peroxide is a powerful bleach. Wash it off with plenty of water if you get it on your skin.

Catalase is found in almost every kind of living cell. It catalyses this reaction:

$$\text{hydrogen peroxide} \xrightarrow{\text{catalase}} \text{water} + \text{oxygen}$$

1 Read through the instructions. Decide what you will observe and measure, and draw a results table.

2 Measure 10 cm^3 of hydrogen peroxide into each of five test tubes or boiling tubes.

3 To each tube, add one of the following substances:
   - **a** some chopped raw potato
   - **b** some chopped boiled potato
   - **c** some fruit juice
   - **d** a small piece of liver
   - **e** some yeast suspension.

4 Light a wooden splint, and then blow it out so that it is glowing. Gently push the glowing splint down through the bubbles in your tubes.

5 Record your observations, and explain them as fully as you can.

Temperature and enzyme activity

Most chemical reactions happen faster at higher temperatures. This is because the molecules have more kinetic energy – they are moving around faster, so they bump into each other more frequently. This means that at higher temperatures an enzyme is likely to bump into its substrate more often than at lower temperatures. They will also hit each other with more energy, so the reaction is more likely to take place (Figure **5.4**).

However, enzymes are damaged by high temperatures. For most human enzymes, this begins to happen from about 40 °C upwards. As the temperature increases beyond this, the enzyme molecules start to lose their shape. The active site no longer fits perfectly with the substrate. The enzyme is said to be **denatured**. It can no longer catalyse the reaction.

The temperature at which an enzyme works fastest is called its **optimum temperature**. Different enzymes have different optimum temperatures. For example, enzymes from the human digestive system generally have an optimum of around 37 °C. Enzymes from plants often have optimums around 28 °C to 30 °C. Enzymes from bacteria that live in hot springs may have optimums as high as 75 °C.

pH and enzyme activity

The pH of a solution affects the shape of an enzyme. Most enzymes are their correct shape at a pH of about 7 – that is, neutral. If the pH becomes very acidic or very alkaline, then they are denatured. This means that the active site no longer fits the substrate, so the enzyme can no longer catalyse its reaction (Figure **5.5**).

Some enzymes have an optimum pH that is not neutral. For example, there is a protease enzyme in the human stomach that has an optimum pH of about 2. This is because we have hydrochloric acid in our stomachs. This protease must be able to work well in these very acidic conditions.

Study tip

Do not say that enzymes are 'killed' by high temperatures. Enzymes are chemicals, not living organisms.

Questions

5.7 What is meant by an optimum temperature?

5.8 What is the optimum temperature for the enzyme in Figure **5.4**?

5.9 Why are enzymes damaged by high temperatures?

Activity 5.2

Investigating the effect of pH on the activity of catalase

Skills

A03.1 Using techniques, apparatus and materials
A03.3 Observing, measuring and recording
A03.4 Interpreting and evaluating observations and data

⚠ Wear eye protection if available.
Hydrogen peroxide is a powerful bleach.
Wash it off with plenty of water if you get it on your skin.

Catalase is a common enzyme which is the catalyst in the breakdown of hydrogen peroxide, H_2O_2. Catalase is found in almost every kind of living cell. Hydrogen peroxide is a toxic substance formed in cells.

The breakdown reaction is as follows:

$$2H_2O_2 \longrightarrow 2H_2O + O_2$$

The rate of the reaction can be determined from the rate of oxygen production.

One indirect but simple way to measure rate of oxygen production is to soak up a catalase solution onto a little square of filter paper and then drop it into a beaker containing a solution of H_2O_2. The paper sinks at first, but as the reaction proceeds, bubbles of oxygen collect on its surface and it floats up.

(continued ...)

(... continued)

The time between placing the paper in the beaker and it floating to the surface is a measure of the rate of the reaction.

In this investigation, you will test this hypothesis: **Catalase works best at a pH of 7 (neutral).**

1 Label five 50 cm^3 beakers pH 5.6, 6.2, 6.8, 7.4, 8.0.

2 Measure 5 cm^3 of 3% hydrogen peroxide solution into each beaker.

3 Add 10 cm^3 of the correct buffer solution to each beaker. (A buffer solution keeps the pH constant at a particular value.)

4 Cut out 20 squares of filter paper exactly 5 mm × 5 mm. Alternatively, use a hole punch to cut out circles of filter paper all exactly the same size. Avoid handling the paper with your fingers, as you may get grease onto it. Use forceps (tweezers) instead.

5 Prepare a leaf extract by grinding the leaves in a pestle and mortar. Add 25 cm^3 of water and stir well.

6 Allow the remains of the leaves to settle and then pour the fluid into a beaker. This fluid contains catalase.

7 Prepare a results table like the one below.

8 Pick up a filter paper square with forceps and dip it into the leaf extract.

9 Make sure you are ready to start timing. Then place the filter paper square at the bottom of the beaker containing H_2O_2 and pH 5.6 buffer solution. (Do not let it fall near the side of the beaker.) As you put the square into the beaker, start a stopwatch. Stop the watch when the paper floats horizontally at the surface.

10 Record the time in your table and repeat steps 8 and 9 twice more.

11 Follow steps 8–10 for each of the other pHs.

12 Pour some of the remaining leaf extract into a test tube and boil for 2 minutes. Cool under a tap.

13 Repeat steps 8–10, using the boiled extract.

14 Calculate the mean (average) time taken at each pH and enter it into your table.

15 Draw a graph to show time taken for flotation plotted against pH and compare with Figure 5.5.

	Time taken for paper to float in seconds				
pH	5.6	6.2	6.8	7.4	8.0
Tests 1					
2					
3					
Mean					
Boiled extract					

Questions

A1 Does the enzyme have an optimum pH? If it does, what do your results suggest it to be?

A2 Do your results support the hypothesis you were testing, or do they disprove it? Explain your answer.

A3 What is the effect of boiling the extract?

A4 Why do the filter paper squares have to be exactly the same size?

A5 In most experiments in biology, we can never be quite sure that we would get exactly the same results if we did it again. There are always some limitations on the reliability of the data that we collect. Can you think of any reasons why the results you got in your experiment might not be absolutely reliable? For example:

- Might there have been any variables that were not controlled and that might have affected the results?
- Were you able to measure the volumes and times as accurately as you would have liked?

Activity 5.3
Investigate the effect of temperature on the activity of amylase

Activity 5.4
Investigating the effect of temperature on the activity of catalase

Summary

You should know:

- how enzymes work as biological catalysts
- how enzymes are named
- S about active sites, substrates and products
- why enzymes are specific for their particular substrates
- how temperature affects enzyme activity
- S why temperature affects enzyme activity
- how pH affects enzyme activity
- S why pH affects enzyme activity
- how to investigate the effect of temperature and pH on enzyme activity
- how to plan and carry out an investigation into enzyme activity.

End-of-chapter questions

1 Explain the meaning of each of these terms:

a enzyme
b denatured
S c substrate
d product
e active site.

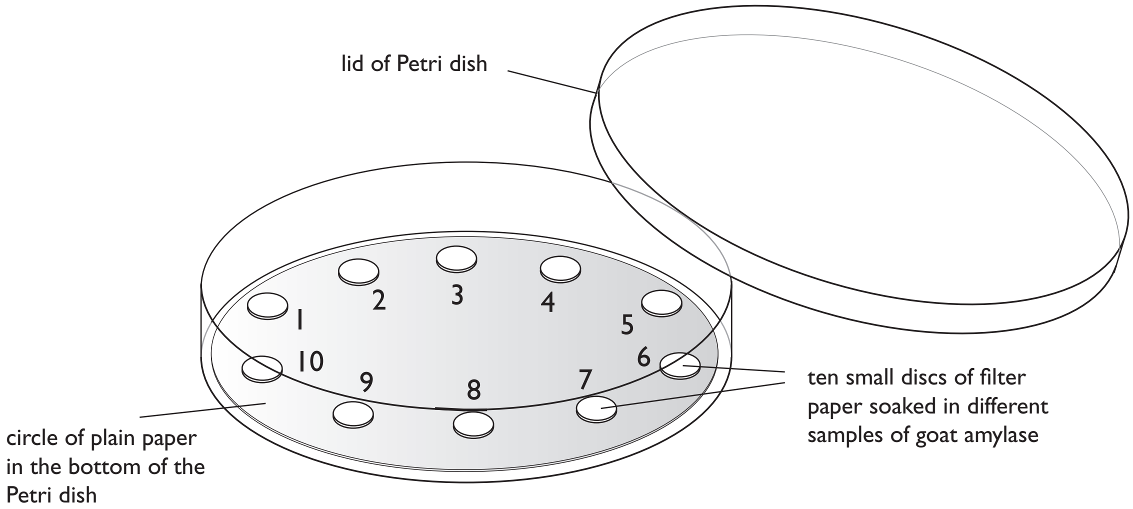
2 A protease enzyme is found in the stomachs of humans. It catalyses the breakdown of long chains of amino acids (proteins) into individual amino acid molecules.

a Suggest the optimum temperature for the activity of this protease enzyme.
b The stomach contains hydrochloric acid. Suggest the optimum pH for the activity of this protease enzyme.
S c Explain why the rate of an enzyme-controlled reaction is relatively slow at low temperatures.
d Explain why the rate of the reaction slows down above the enzyme's optimum temperature.

3 Students investigated samples of amylase from 100 goats. 100 small filter paper discs were each soaked in a different sample of goat amylase. The students tested the activity of these amylase samples using plain paper. Plain paper contains starch.

A circle of plain paper was placed into a Petri dish as shown in the diagram below. Iodine solution was used to stain the starch in the plain paper.

a When iodine solution reacts with the starch in the plain paper, what colour would you see? [1]



Ten amylase soaked filter paper discs were placed into one of the Petri dishes as shown in the diagram above.
Ten Petri dishes were set up as in the diagram.
The students lifted the filter paper discs at one-minute intervals and recorded the number of areas where there had been a reaction.

b How would the students know that a reaction had taken place? [1]

If a reaction had not taken place, the students replaced the disc of filter paper for another minute. This procedure was repeated for five minutes.
Their results are recorded in the table below.

Time / minutes	Number of **new** areas where there had been a reaction	**Total** number of areas where there had been a reaction
1	14	14
2	28	42
3	18	60
4	12	...
5	6	...

c **i** Copy and complete the table by calculating the total number of areas where there had been a reaction after 4 and 5 minutes.
Show your working. [2]

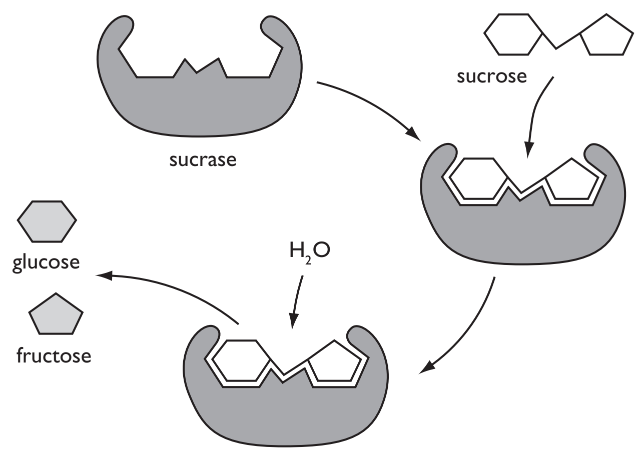
ii Plot a graph using the data from the first two columns, to show the differences in the activity of amylase. [5]

iii Suggest **two** reasons for the differences in amylase activity of the samples. [2]

d Suggest **three** ways in which you could improve this investigation. [3]

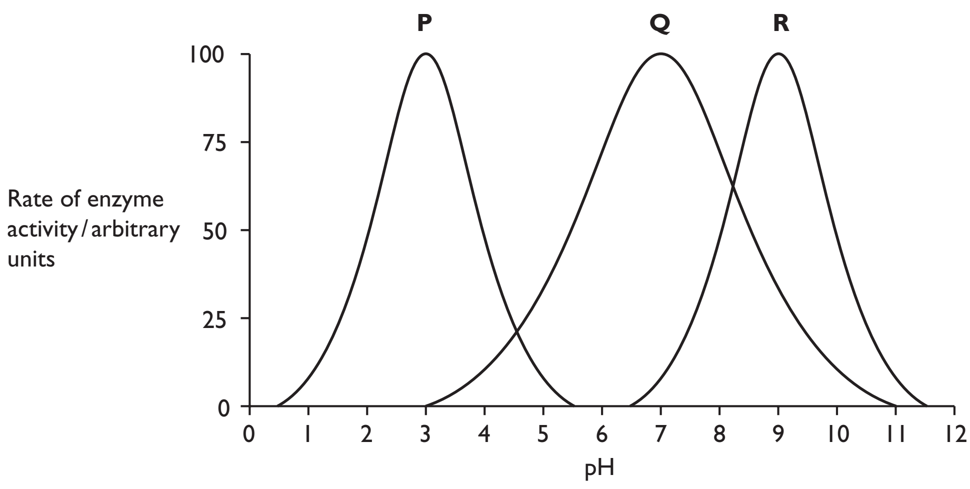
[Cambridge IGCSE® Biology 0610/61, Question 1, May/June 2011]

4 Enzymes are biological catalysts. The diagram below shows how the enzyme, sucrase, breaks down a molecule of sucrose.



a Describe how sucrase catalyses the breakdown of sucrose. You should refer to the diagram above in your answer. [3]

b Three enzymes, **P**, **Q** and **R**, were extracted from different regions of the alimentary canal of a mammal. The effect of pH on the activity of the enzymes was investigated at 40 °C. The results are shown in the diagram below.



i Explain why the investigation was carried out at 40 °C. [2]

ii Using information in the diagram above, describe the effects of increasing pH on the rate of activity of enzyme **Q**. [3]

[Cambridge IGCSE® Biology 0610/33, Question 3, October/November 2010]

6 Plant nutrition

In this chapter, you will find out about:

- how plants make carbohydrates by photosynthesis
- the structure of leaves
- how plants use the glucose they produce in photosynthesis
- how to carry out investigations into photosynthesis
- S the factors that affect the rate of photosynthesis
- why plants need nitrate and magnesium ions.

Using solar energy to make fuels

As the human population continues to grow, we are using more and more fuel to provide energy for our homes, industries and vehicles. A lot of this energy comes from burning fossil fuels, which produces carbon dioxide. The quantity of carbon dioxide in the atmosphere is increasing, contributing to global warming. We need to find alternative ways of providing energy.

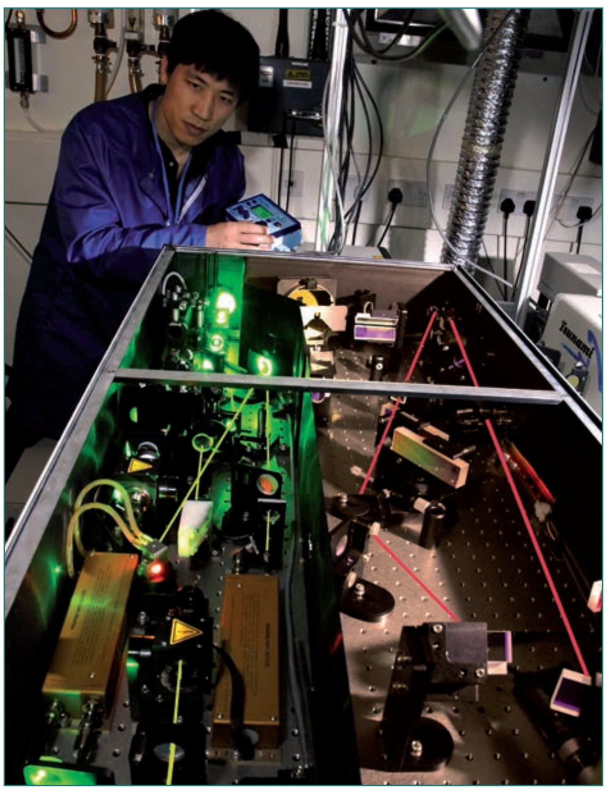


Figure 6.1 Research is being carried out into ways of using solar energy to make hydrogen.

Can we take a lesson from plants? Plants use energy from sunlight to make food that fuels their bodies. They actually use up carbon dioxide in this process. Already, in many parts of the world, plants are being grown not to provide us with food, but to provide us with fuel that can be burnt to produce electricity, or to move vehicles. But this takes up a large amount of land that may be needed to grow food crops, or that would be better left as natural forests or other habitats for wildlife.

So scientists are looking into ways in which we might use a kind of 'artificial photosynthesis' to make hydrogen, which can be used as a fuel (Figure **6.1**).

Plants have an amazing substance called chlorophyll, which captures energy from sunlight and helps to transfer this energy into carbohydrates. Research into artificial photosynthesis is exploring potential substances that might be able to perform the same role, particularly semi-conductors like tungsten diselenide or silicon. The process would use light, water and carbon dioxide – just like plants do. However, instead of producing carbohydrates, we could use artificial photosynthesis to produce hydrogen from water. Hydrogen is a good fuel because it produces only water and not carbon dioxide when it is burnt.

6.1 Types of nutrition

All living organisms need to take many different substances into their bodies. Some of these may be used to make new parts, or repair old parts. Others may be used to release energy. Taking in useful substances is called feeding, or **nutrition**.

Animals and fungi cannot make their own food. They feed on organic substances that have originally been made by plants. Some animals eat other animals, but all the substances passing from one animal to another were first made by plants. Animal nutrition is described in Chapter 7.

Green plants make their own food. They use simple **inorganic** substances – carbon dioxide, water and minerals – from the air and soil. Plants build these substances into complex materials, making all the carbohydrates, lipids, proteins and vitamins that they need. Substances made by living things are said to be **organic**.

6.2 Photosynthesis

Green plants make the carbohydrate glucose from carbon dioxide and water. At the same time, oxygen is produced.

If you just mix carbon dioxide and water together, they will not make glucose. They have to be given energy before they will combine. Green plants use the energy of sunlight for this. The reaction is therefore called **photosynthesis** ('photo' means light, and 'synthesis' means manufacture).

Key definition

photosynthesis the process by which plants manufacture carbohydrates from raw materials using energy from light

Chlorophyll

However, sunlight shining onto water and carbon dioxide still will not make them react together to make glucose. The sunlight energy has to be trapped, and then used in the reaction. Green plants have a substance which does this. It is called **chlorophyll**.

S Chlorophyll is the pigment which makes plants look green. It is kept inside the chloroplasts of plant cells.

S When sunlight falls on a chlorophyll molecule, some of the energy in the light is absorbed. The chlorophyll molecule then releases the energy. The released energy makes carbon dioxide combine with water, with the help of enzymes inside the chloroplast. The glucose that is made contains energy that was originally in the sunlight. So, in this processs, light energy is transferred to chemical energy.

The photosynthesis equation

The full equation for photosynthesis is written like this:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \text{glucose} + \text{oxygen}$$

S To show the number of molecules involved in the reaction, a balanced equation needs to be written. Carbon dioxide contains two atoms of oxygen, and one of carbon, so its molecular formula is CO_2. Water has the formula H_2O. Glucose has the formula $C_6H_{12}O_6$. Oxygen molecules contain two atoms of oxygen, and so they are written O_2.

The balanced equation for photosynthesis is this:

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

Questions

6.1 Give **one** example of an organic substance.

6.2 Which inorganic substances does a plant use to make carbohydrates?

6.3 What is chlorophyll, and how does it help the plant?

6.3 Leaves

Photosynthesis happens inside chloroplasts. This is where the enzymes and chlorophyll are that catalyse and supply energy for the reaction. In a typical plant, most chloroplasts are in the cells in the leaves. A leaf is a factory for making carbohydrates.

Leaves are therefore specially adapted to allow photosynthesis to take place as quickly and efficiently as possible.

Leaf structure

A leaf consists of a broad, flat part called the **lamina** (Figure **6.2**), which is joined to the rest of the plant by a leaf stalk or **petiole**. Running through the petiole are **vascular bundles**, which then form the veins in the leaf. These contain tubes which carry substances to and from the leaf.

Although a leaf looks thin, it is in fact made up of several layers of cells. You can see these if you look at a transverse section (TS) of a leaf under a microscope (Figures **6.3**, **6.4** and **6.5**).

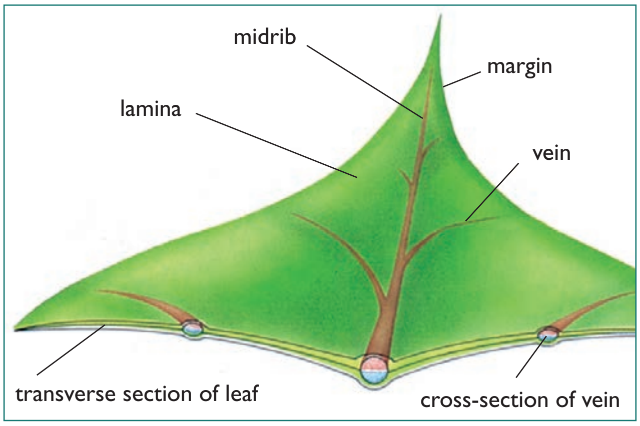


Figure 6.2 The structure of a leaf.

The top and bottom of the leaf are covered with a layer of closely fitting cells called the **epidermis** (Figures **6.6** and **6.7**). These cells do not contain chloroplasts. Their function is to protect the inner layers of cells in the leaf. The cells of the upper epidermis often secrete a waxy substance, that lies on top of them. It is called the **cuticle**, and it helps to stop water evaporating from the leaf. There is sometimes a cuticle on the underside of the leaf as well.

In the lower epidermis, there are small openings called **stomata** (singular: **stoma**). Each stoma is surrounded by a pair of sausage-shaped **guard cells** which can open or close the hole. Guard cells, unlike other cells in the epidermis, do contain chloroplasts.

The middle layers of the leaf are called the **mesophyll** ('meso' means middle, and 'phyll' means leaf). These cells all contain chloroplasts. The cells nearer to the top of the leaf are arranged like a fence or palisade, and they form the **palisade layer**. The cells beneath them are rounder, and arranged quite loosely, with large air spaces between them. They form the **spongy layer** (Figure **6.3**).

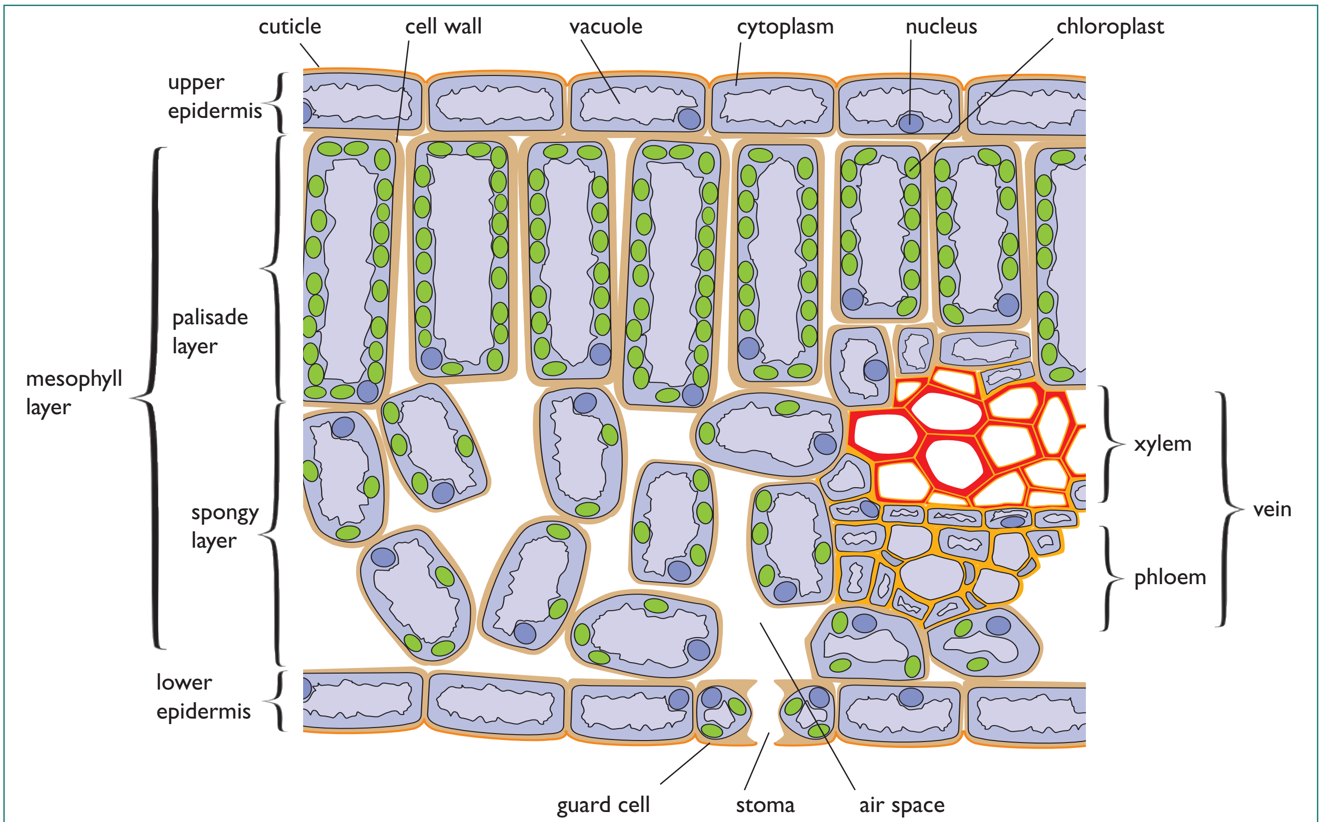


Figure 6.3 Transverse section through a small part of a leaf.