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Cambridge O Level

Biology

D G Mackean
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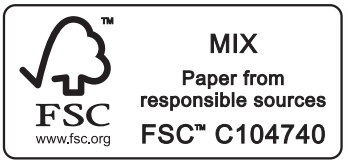

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How to use this book

To make your study of Biology for Cambridge O Level as rewarding and successful as possible, this textbook, endorsed by Cambridge Assessment International Education, offers the following important features:

Focus

Each chapter starts with a short outline of the topic so you know what to expect within each chapter.

FOCUS POINTS

Each topic starts with a bullet point summary of what you will encounter over the next few pages.

Test yourself

These questions appear regularly throughout the topic so you can check your understanding as you progress.

Revision checklist

At the end of each chapter, a revision checklist allows you to recap what you have learned and double check that you understand the key concepts before moving on.

Exam-style questions

Each chapter is followed by exam-style questions to help familiarise you with the style of questions you may see in your examinations. These will also prove useful in consolidating your learning. Past paper questions are also provided in the back of the book.

Key definitions

These provide explanations of the meanings of key words as required by the syllabus. Terms highlighted in red are in the glossary.

Practical work

These boxes identify the key practical skills you need to be able to understand and apply as part of completing the course.

Worked example

These boxes give step-by-step guidance on how to approach different sorts of calculations, with follow-up questions so you can practise these skills.

Going further

These boxes take your learning further than is required by the syllabus if you choose to broaden your understanding.

In some places, content in the main body of this book may go beyond syllabus requirements, but has been included to add useful context. Where this occurs, this will be flagged with a note beside the text. For example, on page 218 details of some parts of the eye are not required by the syllabus but have been included to aid understanding.

Answers are provided online at www.hoddereducation.com/cambridgeextras.

Scientific enquiry

During your course you will do several experiments and investigations. These will help you to develop some of the **skills** and **abilities** that scientists use to solve real-life problems.

Simple experiments may be designed to measure, for example, your pulse rate while you are resting. Longer investigations may be designed to establish or confirm a relationship between two or more physical quantities, for example, the effect of increasing temperature on the rate of transpiration in a plant shoot. Investigations will likely be generated from the topic you are currently studying in class.

Any investigation will involve the following five aspects:

1. **Selecting and safely using techniques, apparatus and materials** – you need to be aware of any hazards presented by an investigation and how you will minimise any possible risks. Your teacher should help you with any risk assessments before you start. You also need to be able to identify the best materials and equipment in order to make sure you stay safe and that your observations or data are accurate.
2. **Planning experiments** – when planning you need to consider what procedure will help you find answers to the questions you are investigating. When choosing the apparatus or technique you will use, think about the reasons for your choice. Once you've selected these it will be useful to make predictions and hypotheses (informed guesses) of the results you'd expect. It will help to write down your plan as it develops.
   Variables are also very important in planning – you will need to identify both the independent variables and the dependent variable so you can make sure the results are valid. You will need to consider how the independent variables will be controlled and what range of values you intend to collect. Decide how you will process the results in order to form a conclusion or to evaluate your prediction.
3. **Making and recording observations, measurements and estimates** – you must make sure you measure and collect the necessary experimental data with suitable precision. This involves selecting and using the most appropriate measuring instruments available to you. You need to choose an appropriate number of readings or observations, remembering to include repeats to check your data are reliable. The results will need to be recorded systematically (e.g. in a suitable table). If you're recording observations be sure to be detailed.
4. **Interpreting and evaluating the observations and data** – when evaluating results you need to do so in a way that enables any relationships between quantities to be formed. As part of this, you will need to process the information you have collected. This may involve calculations, such as working out the percentage change in mass of samples of potato when placed in a range of sucrose solutions. Alternatively, you may need to plot a graph, for example, to show the relationship between temperature and the rate of enzyme action. Always make sure any graph axes are labelled with the descriptor and units on both axes (these details can be taken from your table headers).
   When forming conclusions, you need to state the relationship your data has established (what happens to the dependent variable as the independent variable is changed) and give a scientific explanation for why it has happened. You should be aware of the possibility of any anomalous results and decide how to treat these. If you were to evaluate the data, how could you have improved the accuracy, reliability or quality? What would you do differently next time?
5. **Evaluating experimental methods and suggesting possible improvements** – this is different than evaluating your data and requires you to look at the investigation as a whole. You should assess the techniques you used and decide whether your use of a control was adequate. You should also identify any possible sources of error, deciding how you could have overcome these. It may be that you had difficulty measuring the change in length of a piece of potato with a ruler in an osmosis investigation. Instead of measuring length, weighing the potato pieces on a digital balance could provide more accurate data.

A written report of the investigation is normally made, and this should include:

- An aim – what you are trying to find out.
- A plan of what you intend to do. This should include the apparatus needed for your experiments, including justifications for your choice, safety precautions, identification of the

variables and how you will control them, and predictions of expected results. You should draft out a table with suitable headings (and don't forget to state units) for recording any data you intend to collect.

- When listing items of apparatus you will use, make a record of the smallest division of the scale of any measuring device. For example, the smallest division on a metre rule is 1 mm. The scale of the rule can be read to the nearest mm. So, when used to measure a length of 100 mm (0.1 m), the length is measured to the nearest 1 mm, and the degree of accuracy of the measurement is 1 part in 100. When used to measure 10 mm (0.01 m), the degree of accuracy of the measurement is 1 part in 10.
  As another example, a thermometer is calibrated in degrees Celsius and may be read to the nearest 1 °C. A temperature may be measured to the nearest 1 °C. So, when used to measure a temperature of 20 °C, the degree of accuracy is 1 part in 20 (this is 5 parts in 100). If a digital thermometer is available, this may be a better choice for accuracy.
- A method – this should include the details of any procedures, observations and measurements you carry out. A clearly labelled diagram of the apparatus is a good way of supporting your method. When labelling the apparatus, avoid label lines crossing each other.
- Presentation of results and calculations. Any data you collected should be clearly presented (most likely in a table). The column headings, or start of rows, should include a descriptor (naming the measurement) and its unit; for example, 'temperature / °C'. If you have repeated any measurements, calculate an average value. Numerical values should be given to the number of significant figures appropriate to the measuring device you used in collecting the data. If it is appropriate to plot a graph of your results, you will need at least five data points taken over as large a range as possible. Remember to label each axis of a graph with the descriptor and unit of the quantity being plotted. Also put a title on the graph. This will refer to both axes of the graph, for example, 'Graph to show the effect of increasing temperature on the rate of action of amylase on starch.'
- A concise conclusion should be drawn from the evidence. This can be based on the prediction, stating the relationship between the two quantities you investigated. Note that sometimes experiments do not achieve the intended objective. If this is the case, a conclusion is still important. A conclusion must be a description of the pattern as well as a scientific explanation for this trend.
- In order to produce an evaluation and discussion of the result of the investigation you need to look critically at your procedure. Points to include are:
  - commenting critically on the original plan
  - evaluating the procedures used
  - deciding how reliable the results are. The reliability can be indicated by how close any repeated readings are. You could compare your results with secondhand evidence (such as from a graph in a textbook) to consider whether or not the evidence can be trusted
  - using a systematic approach to dealing with unexpected results. For example, if you took a reading that was unexpected, did you take a further reading? Can you identify why that reading might have been incorrect?
  - considering how appropriate the apparatus used in the investigation was and suggesting improvements where appropriate.

Drawing skills

A biological drawing should provide an accurate representation of a biological specimen. It is not the same as an artist's drawing. By following a few rules and practising, you will be able to produce good biological drawings. Here are some helpful tips.

- Practice drawing everyday objects, such as laboratory glassware or a Bunsen burner.
- Move on to large biological specimens, for example, a mammal limb bone, a simple flower, a large seed or a leaf.
- Start using a hand lens to observe and draw specimens e.g. cockroach leg or insect wing.
- Finally, if the equipment is available, draw microscope specimens (see Chapter 1 for practical work on preparing microscope slide specimens and use of the microscope).
- Using a sharp HB pencil, make drawings as large as possible to fit into the space available.
- Outlines should be sharp and clear, rather than sketchy.

- Avoid unnecessary shading, as it can often cover important detail.
- On the drawing, show any detail that can be observed.
- If the use of a hand lens is required, show on the drawing some detail that can only be seen clearly using the lens.

Labelling the drawing

- Label if told to do so.
- Use ruled label lines in pencil.
- The label lines must finish precisely on the relevant feature.
- Labels should be written in pencil.

Getting proportions right

- The relative proportions of the parts of the specimen should be correctly represented.
- Drawings should show the correct number of parts and details as seen in the specimen.
- The drawing should show what has been asked for. For example, if a whole specimen is required, draw all of what can be seen. If one part is required e.g. a leg only, then just draw the part.

Suggestions for investigations

Some of the suggested investigations in this book include:

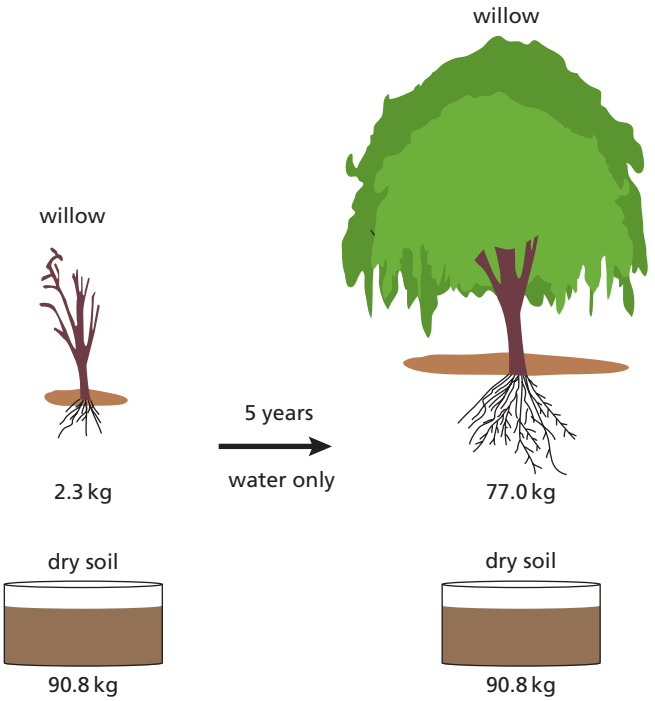
1. The factors that influence diffusion (Chapter 3).
2. Osmosis, using dialysis tubing, and the effects of different concentrations of solutions on plant tissues (Chapter 3).
3. Food tests (Chapter 4).
4. The effects of changes in temperature and pH on enzyme activity (Chapter 5).
5. The requirements for photosynthesis, rate of photosynthesis, and the effect of light and dark conditions on gas exchange in an aquatic plant (Chapter 6).
6. The pathway of water through the above-ground parts of a plant (Chapter 7).
7. The effects of variation of temperature and wind speed on transpiration rate (Chapter 7).
8. The effect of physical activity on the heart rate (Chapter 11).
9. The differences in composition between inspired and expired air (Chapter 9).
10. The effects of physical activity on the rate and depth of breathing (Chapter 9).
11. The effect of temperature on respiration in yeast (Chapter 10).
12. Gravitropism and phototropism in shoots and roots (Chapter 15).
13. The environmental conditions that affect germination of seeds (Chapter 16).
14. Continuous and discontinuous variation (Chapter 17).
15. The use of biological washing powders that contain enzymes (Chapter 18).

Ideas and evidence in science

When you share the results of an investigation you have performed with your friends and compare their findings with your own, you may find that you do not interpret your data in the same way as your friends do. This could generate a discussion about the best way to explain your results. You may even try to persuade them that your interpretation is the right one. Scientific ideas often change through people interpreting evidence differently, or through new discoveries being made.

Jean-Baptiste van Helmont was a Dutch scientist working in the 17th century. At that time scientists did not know much about the process of photosynthesis. He carried out an experiment using a willow shoot. He planted the shoot in a container with 90.8 kg of dry soil. He placed a metal grill over the soil to stop any accidental gain or loss of mass. He then left the shoot for 5 years in an open place, giving it only rainwater and distilled water for growth. After 5 years he reweighed the tree and the soil (see Figure 1). He concluded that the increase in mass of the tree (74.7 kg) was because of the water it had received. However, he did not know that plants also take in mineral ions and carbon dioxide, or that they use light as a source of energy. Indeed, carbon dioxide was not discovered until one hundred years later, by a Scottish scientist called Joseph Black.

We now know that plants take in water and carbon dioxide, using energy from light to make carbohydrates. We call the process photosynthesis. Plants also need minerals to form other molecules, such as magnesium to make chlorophyll and nitrates to form proteins.



▲ **Figure 1** Van Helmont's experiment

Scientists are constantly doing research which provides new evidence, and they evaluate that evidence. However, that can generate controversy and sometimes there is an unwillingness to accept the scientific findings. This can be the case especially if there are vested social or economic interests involved. Examples of this are the issues of global warming (Chapter 19) and the control of the virus COVID-19.

1 Cells

Focus

In this chapter you will discover the main differences between animal, plant and bacterial cells, as well as the functions of their parts. Within an organism there are levels of organisation. By the end of the chapter you will be able to name these and describe examples from animals and plants. Why are cells different shapes? What jobs do they do? How can we work out their magnification when looking at them? By studying the chapter carefully and following the practical suggestions you should be able to answer these questions.

Cell structure and organisation

FOCUS POINTS

- ★ What are the structures and functions of plant, animal and bacterial cells?
- ★ How do you identify cell structures in diagrams and images of animal, plant and bacterial cells?
- ★ What are the differences between a plant and an animal cell?
- ★ How are new cells produced?
- ★ What are the specific functions of these specialised cells:
  - ★ ciliated cells
  - ★ root hair cells
  - ★ palisade mesophyll cells
  - ★ neurones
  - ★ red blood cells
  - ★ sperm and egg cells (gametes)?
- ★ What are the meanings of the terms cell, tissue, organ, organ system and organism?

Cell structure

If a very thin slice of a plant stem is cut and studied under a microscope, the stem appears to consist of thousands of tiny, box-like structures. These structures are called **cells**. Figure 1.1 is a thin slice taken from the tip of a plant **shoot** and photographed through a microscope. It is 60 times larger than life, so a cell which appears to be 2 mm long in the picture is only 0.03 mm long in reality.

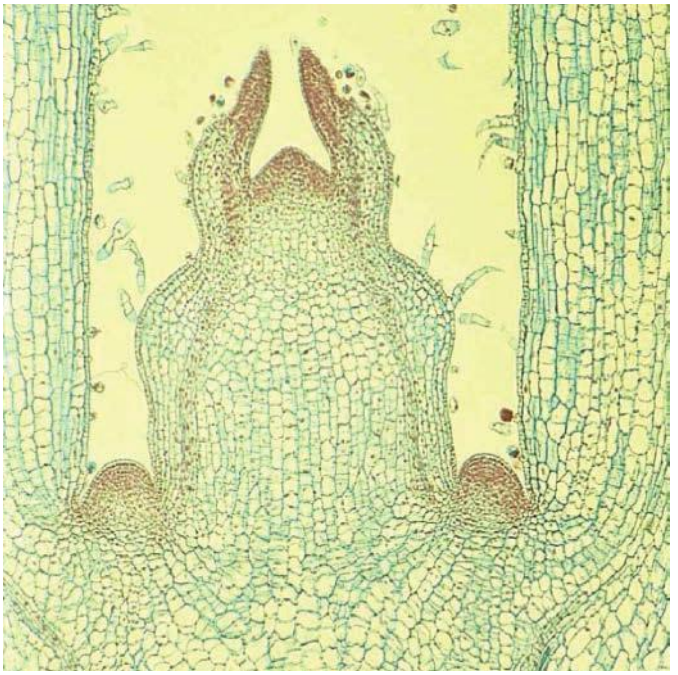
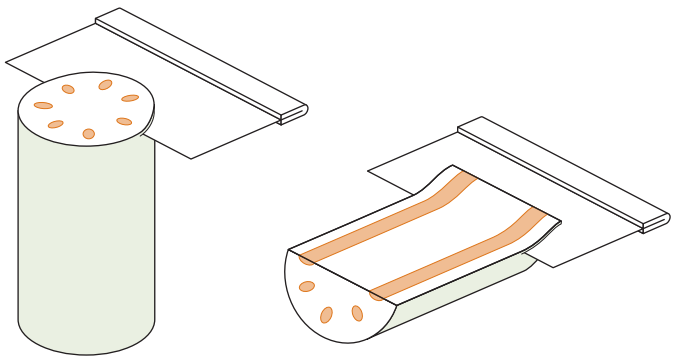


Figure 1.1 Longitudinal section through the tip of a plant shoot (×60). The slice is only one cell thick, so light can pass through it and allow the cells to be seen clearly

Thin slices like this are called sections. If you cut *along the length* of the structure, you are taking a longitudinal section (Figure 1.2(b)). Figure 1.1 shows a longitudinal section, which passes through two small developing leaves near the tip of the shoot, and two larger leaves below them. The leaves, buds and stem are all made up of cells. If you cut *across* the structure, you make a transverse section (Figure 1.2(a)).

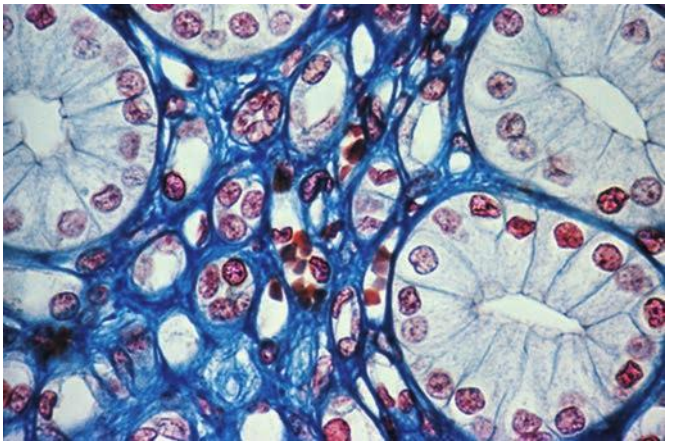


(a) transverse section **(b)** longitudinal section

▲ **Figure 1.2** Cutting sections of a plant stem

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

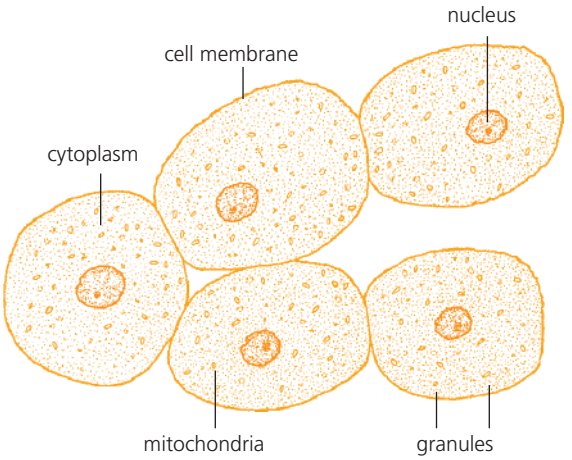
When sections of animal structures are examined under the microscope, they too are seen to be made up of cells, but they are much smaller than plant cells and need to be magnified more. The photomicrograph of kidney **tissue** in Figure 1.3 has been magnified 700 times to show the cells clearly. The sections are often treated with dyes, called stains, in order to make the structures inside the cells show up more clearly.



▲ **Figure 1.3** Transverse section through a kidney tubule (×700). A section through a tube will look like a ring (see Figure 1.7(b)). In this case, each 'ring' consists of about 12 cells

Making sections is not the only way to study cells. Thin strips of plant tissue, only one cell thick, can be pulled off stems or leaves (experiment 1, pages 7–8). Plant or animal tissue can be squashed or smeared on a microscope slide (experiment 2, page 8), or treated with chemicals to separate the cells before studying them.

There is no such thing as a typical plant or animal cell because cells vary a lot in their size and shape depending on their function. However, it is possible to make a drawing, like that in Figure 1.4, to show the features that are present in most cells. All cells have a **cell membrane**, which is a thin boundary enclosing the **cytoplasm**. Most cells have a **nucleus**.



▲ **Figure 1.4** A group of liver cells. These cells have all the characteristics of animal cells

Cytoplasm

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

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

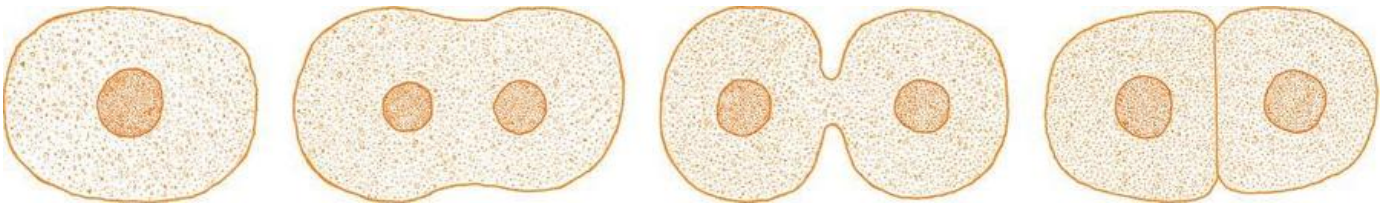
Cell membrane

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

Nucleus (plural: nuclei)

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

When existing cells divide, new cells are produced. The nucleus controls cell division, as shown in Figure 1.5. A cell without a nucleus cannot reproduce. Inside the nucleus are thread-like structures called **chromosomes**, which can be seen most easily at the time when the cell is dividing (see Chapter 16 for a fuller account of chromosomes and cell division).



(a) Animal cell about to divide.

(b) The nucleus divides first.

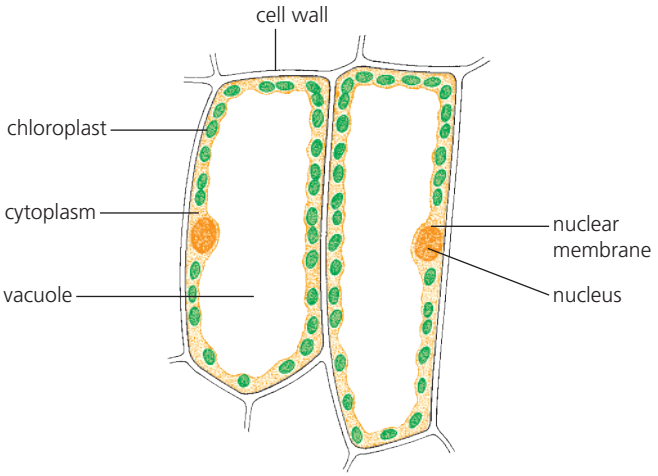
(c) The daughter nuclei separate and the cytoplasm pinches off between the nuclei.

(d) Two cells are formed – one may keep the ability to divide, and the other may become a specialised cell.

▲ **Figure 1.5** Cell division in an animal cell

Plant cells

A few generalised animal cells are shown in Figure 1.4, while Figure 1.6 is a drawing of two palisade cells from a plant leaf. (See 'Leaf structure' in Chapter 6.)



▲ **Figure 1.6** Palisade cells from a leaf

Plant cells differ from animal cells in several ways because they have extra structures: a cell wall, **chloroplasts** and sap **vacuoles**.

Cell wall

The cell wall, which is outside the membrane, contains **cellulose** and other compounds. It is non-living and allows water and dissolved substances to pass through it. The cell wall is not selective like the cell membrane. (**Note:** Plant cells *do* have a cell membrane, but it is not easy to see or draw because it is pressed against the inside of the cell wall (see Figure 1.7).)

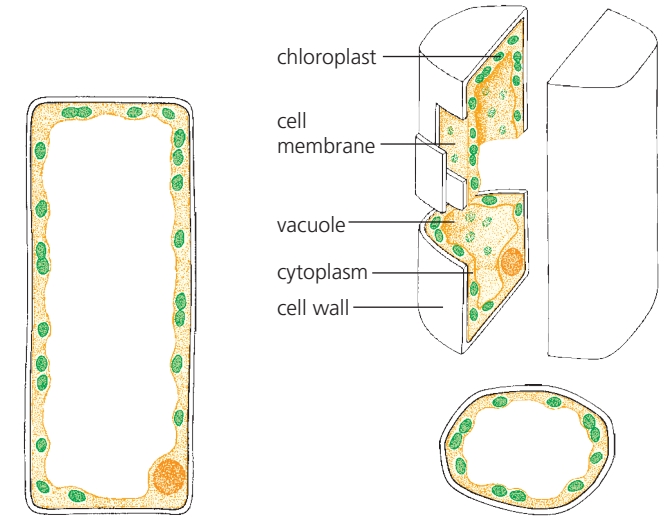
Under the microscope, plant cells are quite distinct and easy to see because of their cell walls. In Figure 1.1 it is only the cell walls (and in some cases the nuclei) that can be seen. Each plant cell has its own cell wall but the boundary between two cells side by side does not usually show up clearly. So, cells next to each other appear to be sharing the same cell wall.

Vacuole

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

Chloroplasts

Chloroplasts are organelles that contain the green substance **chlorophyll** (see Chapter 6).



(a) longitudinal section **(b)** transverse section

▲ **Figure 1.7** Structure of a **palisade mesophyll** cell. It is important to remember that, although cells look flat in sections or in thin strips of tissue, they are three-dimensional and may seem to have different shapes depending on the direction in which the section is cut. If the cell is cut across it will look like (b); if cut longitudinally it will look like (a)

The shape of a cell when seen in a transverse section may be quite different from when the same cell is seen in a longitudinal section, and Figure 1.7 shows why this is so. Figures 7.8(b) and 7.8(c) on page 105 show the appearance of cells in a stem **vein** as seen in transverse and longitudinal sections.

▼ **Table 1.1** Summary: the parts of a cell

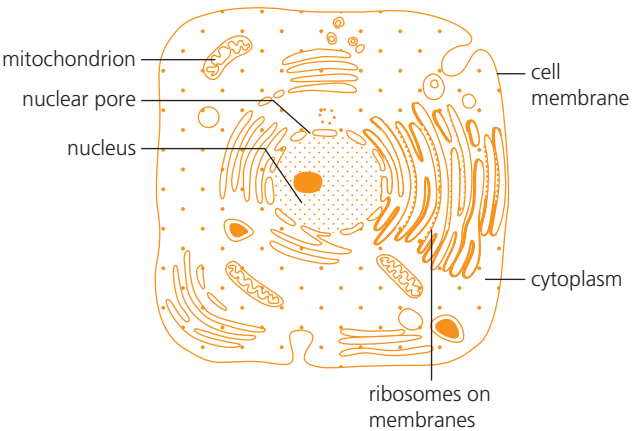
	Name of part	Description	Where found	Function
Animal and plant cells	cytoplasm	jelly-like with particles and organelles in	enclosed by the cell membrane	contains the cell organelles, e.g. **mitochondria** and nucleus site of chemical reactions
	cell membrane	a **partially permeable** layer that forms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

When studied at much higher **magnifications** with the electron microscope, the cytoplasm of animal and plant cells no longer looks like a structureless jelly. It appears to be organised into a complicated system of membranes and vacuoles. Ribosomes are one of the organelles present. They may be held on a membrane but can also be found free in the cytoplasm. They build up the cell's proteins (see Chapter 4).

Mitochondria are tiny organelles, which may appear slipper-shaped, circular or oval when viewed in sections. In three dimensions, they may be spherical, rod-like or extended. They have an outer membrane and an inner membrane with many inward-pointing folds. Mitochondria are most frequent in regions of rapid chemical activity. They are responsible for releasing energy from food substances through the process of **aerobic respiration** (see Chapter 10).

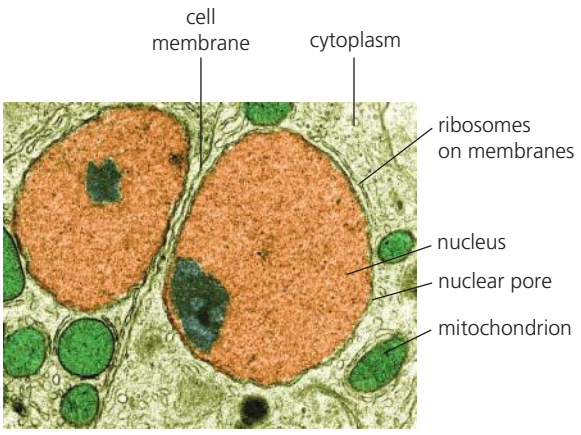
Figure 1.8(a) is a diagram of an animal cell magnified 10 000 times. Figure 1.8(b) is an electron micrograph of a liver cell. Organelles in the cytoplasm can be seen clearly. They have recognisable shapes and features.

Figure 1.8(c) is an electron micrograph of a plant cell. As well as the organelles already named and described, other organelles are also present, like chloroplasts and a cell wall.

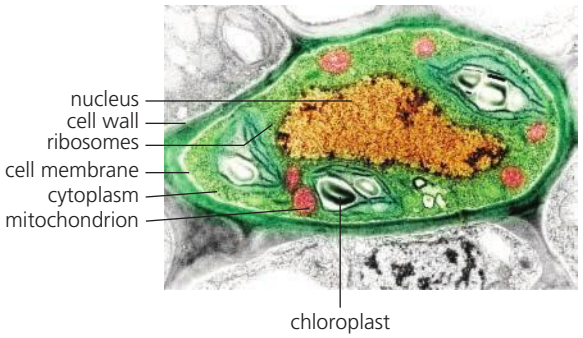


(a) diagram of a liver cell (×10 000)

▲ **Figure 1.8** Cells at high magnification



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



(c) electron micrograph of a plant cell (×6 000)

▲ **Figure 1.8** Cells at high magnification (continued)

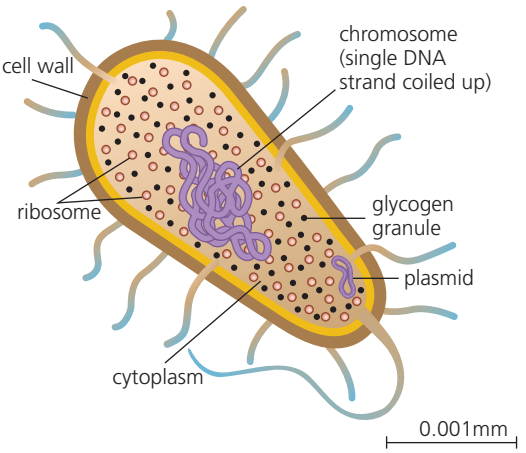
Test yourself

1 a What structures are usually present in both animal and plant cells?
  b What structures are present in plant cells but not in animal cells?
2 What cell structure is mainly responsible for controlling the entry and exit of substances into or out of the cell?
3 How does a cell membrane differ from a cell wall?

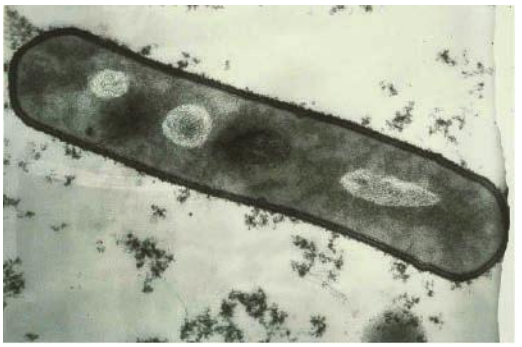
Bacterial cell structure

Bacteria (singular: **bacterium**) are very small **organisms** that are single cells not often more than 0.01 mm in length. They can be seen only at high magnification under a microscope.

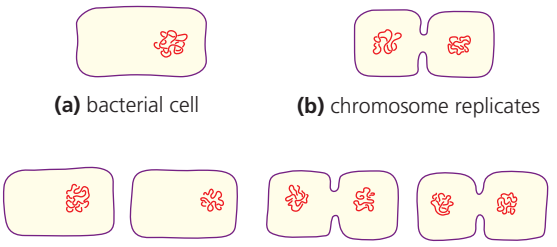
They have a cell wall made of a complicated mixture of proteins, sugars and lipids. (You will remember that plant cell walls are made of cellulose.) Inside the cell wall is the cytoplasm, which may contain granules (small particles) of **glycogen**, lipid and other food reserves (see Figure 1.9). Large numbers of ribosomes float freely in the cytoplasm. They are smaller than the ribosomes found in plant and animal cells but have the same function of protein synthesis.



▲ **Figure 1.9** Generalised diagram of a bacterium



▲ **Figure 1.10** Longitudinal section through a bacterium (×27 000). The light areas are coiled DNA strands. There are three of them because the bacterium is about to divide twice (see Figure 1.11)



(a) bacterial cell **(b)** chromosome replicates

(c) cell divides **(d)** each cell divides again

▲ **Figure 1.11** Bacterium reproducing. This is asexual reproduction by cell division (see 'Asexual reproduction' and 'Mitosis' in Chapter 16)

Each bacterial cell contains a single chromosome made of a circular strand of DNA (see Chapter 17). The chromosome is not surrounded by a nuclear membrane but is coiled up to fill a small part of the cell, as shown in Figure 1.10. There are also smaller circular structures called **plasmids**, which are also made of DNA. Plasmids are used by scientists in the process of

genetic modification because it is relatively easy to insert genetic material into them (see Chapter 18).

Bacteria can be different shapes: they may be spherical, rod-shaped or spiral.

The functions of the structures in a bacterium are shown in Table 1.2.

▼ **Table 1.2** Summary: the parts of a bacterial cell

Name of part	Description	Where found	Function
cytoplasm	jelly-like, contains particles and organelles	surrounded by the cell membrane	contains cell structures, e.g. ribosomes, circular DNA, plasmids
cell membrane	a partially permeable layer that surrounds the cytoplasm	around the cytoplasm	prevents cell contents from escaping controls what substances enter and leave the cell
circular DNA	a single circular chromosome	inside the cytoplasm	controls cell division controls cell development controls cell activities
plasmids	small, circular pieces of DNA	inside the cytoplasm	contain **genes** that carry genetic information to help the process of the survival and **reproduction** of the bacterium
ribosomes	small, circular structures	inside the cytoplasm	protein synthesis
cell wall	a tough, non-living layer (not made of cellulose) that surrounds the cell membrane	around the outside of the bacterial cell	prevents the cell from bursting, allows water and salts to pass through (freely permeable)

Practical work

Safety

- Eye protection must be worn.
- Take care when using a scalpel, follow your teacher's guidance.
- Take care using the iodine solution and methylene blue stains – they will stain skin and clothing.

Looking at cells

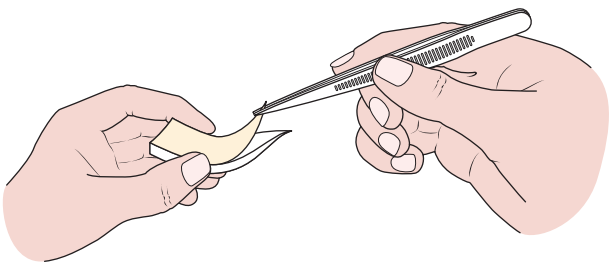
1 Plant cells – preparing a slide of onion **epidermis** cells

The onion contains a very useful source of epidermal plant tissue which is one cell thick. This makes it quite easy to set up as a temporary slide. The onion is made up of fleshy leaves. On the incurve of each leaf there is an epidermal layer which can be peeled off (Figure 1.12(a)).

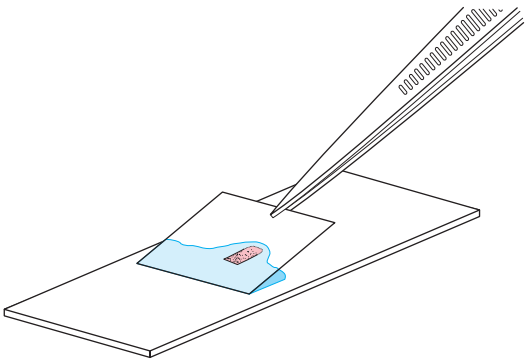
- Using forceps, peel a piece of epidermal tissue from the incurve of an onion bulb leaf.
- Place the epidermal tissue on a glass microscope slide.
- Using a scalpel, cut out a 1 cm square of tissue (throw away the rest) and arrange it in the centre of the slide.
- Add two to three drops of **iodine solution**. (This stains any starch in the cells and makes different parts of the cells distinct.)
- Using forceps, a mounted needle or a wooden splint, support a cover-slip with one edge resting near to the onion tissue, at an angle of about 45° (Figure 1.12(b)).
- Gently lower the cover-slip over the onion tissue. Try to avoid trapping any air bubbles. (Air bubbles reflect light when viewing under the light microscope, hiding the features you are trying to see.)

- Leave the slide for about 5 minutes. This allows the iodine solution stain to react with the specimen. The iodine solution stains the cell nuclei pale yellow and the starch grains blue.
- Place the slide on to the microscope stage, choose the lowest power objective lens and focus on the specimen. Increase the magnification using the other objective lenses. Under high power, the cells should look like those shown in Figure 1.13.

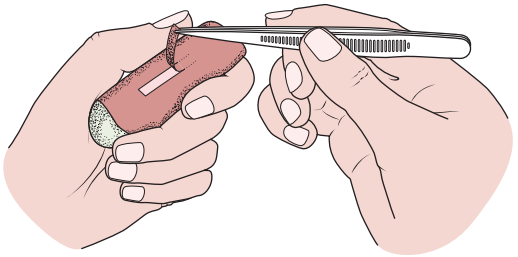
An alternative tissue is rhubarb epidermis (Figure 1.12(c)). You can strip this off from the surface of a stalk and treat it in the same way as the onion tissue. If you use red epidermis from rhubarb stalk, you will see the red cell sap in the vacuoles.



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

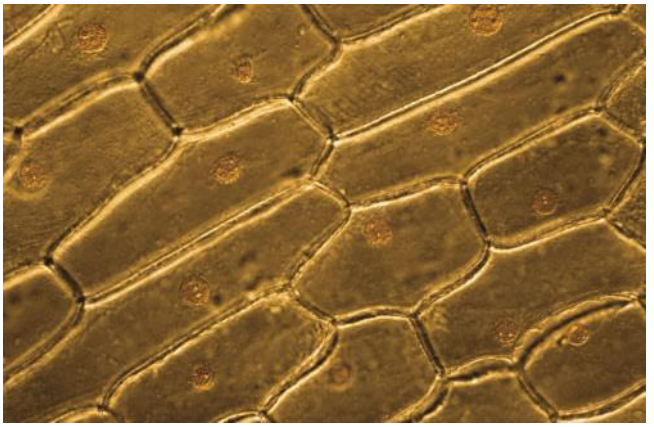


(b) place the epidermis on to the slide, adding 2–3 drops of iodine solution and carefully lower a cover-slip on to it



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

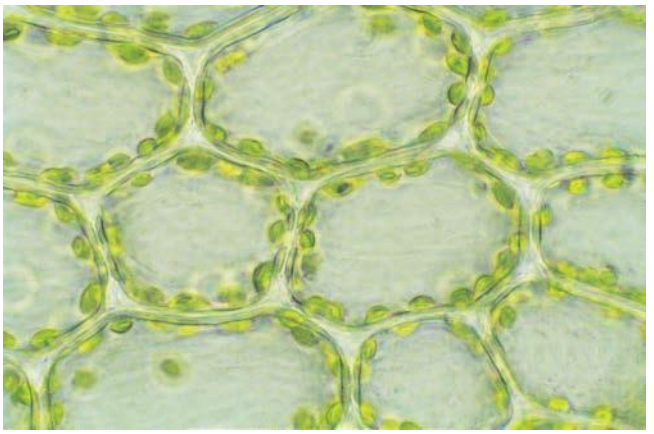
▲ **Figure 1.12** Looking at plant cells



▲ **Figure 1.13** Onion epidermis cells

2 Plant cells – preparing cells with chloroplasts

- Using forceps, remove a leaf from a moss plant.
- Place the leaf in the centre of a microscope slide and add one or two drops of water.
- Place a cover-slip over the leaf.
- Examine the leaf cells with the high power objective of a microscope. The cells should look like those shown in Figure 1.14.



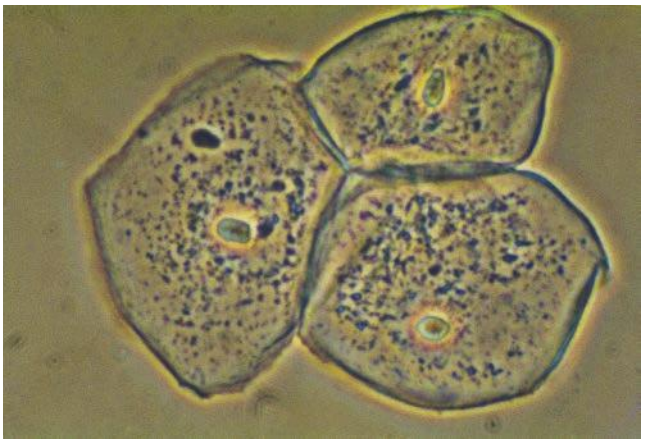
▲ **Figure 1.14** Cells in a moss leaf (×500). The vacuole occupies most of the space in each cell. The chloroplasts are limited to the layer of cytoplasm lining the cell wall

3 Animal cells – preparing human cheek cells

Human cheek cells are constantly being wiped off the inside of the mouth when the tongue and food rub against them, so they can be collected easily for use in a temporary slide.

Note: Check local guidance to whether observing cheek cells is permitted. Use appropriate precautions to treat contaminated items with disinfectant or by autoclaving.

- Rinse your mouth with water. This will remove any fragments of food.
- Take a cotton bud from a freshly opened pack. Rub the cotton bud lightly on the inside of your cheek and **gums** to collect some cheek cells in **saliva**.
- Rub the cotton bud on to the centre of a clean microscope slide, leaving a sample of saliva. Repeat if the sample is too small. Then drop the cotton bud into a container of absolute alcohol or disinfectant.
- Add two to three drops of methylene blue dye. (This stains parts of the cheek cells to make nuclei more visible.)
- Using forceps, a mounted needle or wooden splint, support a cover-slip with one edge resting near to the cheek cell sample, at an angle of about 45°. Gently lower the cover-slip over the tissue. Try to avoid trapping any air bubbles. (Air bubbles reflect light when viewing under the light microscope, hiding the features you are trying to see.)
- Leave the slide for a few minutes. This allows the methylene blue stain to react with the specimen.



▲ **Figure 1.15** Cells from the lining epithelium of the cheek (×1 500)

- Place the slide on to the microscope stage, choose the lowest power objective lens and focus on the specimen. Increase the magnification using the other objective lenses. Under high power, the cells should look like those shown in Figure 1.15, but less magnified.
- When you have completed the 'Test yourself' section on the following page, place your used slide in laboratory disinfectant before washing.

4 Animal cell – preparing human skin cells

You can try another method of obtaining cells if the previous method is not suitable.

- Wash your wrist well, then press some transparent sticky tape on to the cleaned area of skin.
- Remove the tape and stick it to a microscope slide.
- Place the slide on the microscope stage.
- Look for cells. You should be able to see nuclei in them.
- If you add a few drops of methylene blue solution before putting the tape on the slide, the cells take up the stain and it makes the nuclei more distinct.

Practical work questions

1 In experiment 1, what cell structures could you identify in the onion cells you observed?

2 a For experiment 3, explain why the chloroplasts appear to be pressed against the cell wall of the cell.

b Why are the chloroplasts green?

3 For experiment 3, explain why it is necessary to use a stain when preparing specimens of cells.

4 In experiments 3 and 4, the skin cells are animal epidermal cells. Plants also have epidermal cells. Compare a human skin epidermal cell with an upper epidermal cell of a leaf (see Figure 6.22 on page 95).
What cell structures do leaf epidermal cells have which are *not* present in human epidermal cells?

Test yourself

4 How is a bacterial cell different from a plant cell?
5 Bacteria and plant cells both have a cell wall. In what way are the cell walls different?
6 Make a large drawing of **one** cell and label the following parts: cell wall, cell membrane, cytoplasm, nucleus.
7 Make a note of the magnification of the eyepiece and objective lenses of your microscope.
8 Copy and complete the table by
   a writing the magnification of the eyepiece lens
   b writing the magnification of the objective lens of your microscope which you used to make your drawing
   c calculating total magnification provided by the microscope.

magnification of the eyepiece lens	
magnification of the objective lens	
total magnification provided by the microscope	

9 Estimate how much bigger your drawing is than the image you see through the microscope. Use these figures to calculate the total magnification of your drawing.

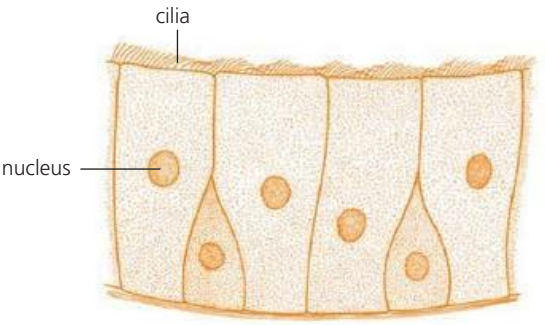
Specialisation of cells

When cells have finished dividing and growing, most become **specialised** and have specific functions. When cells are specialised:

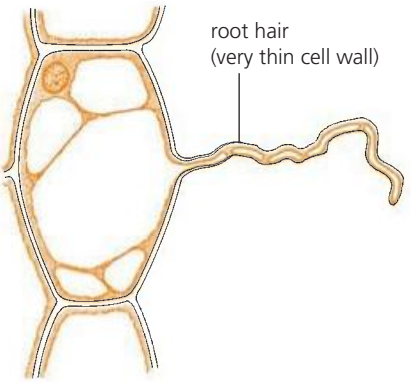
- they do one special job
- they develop a distinct shape
- special kinds of chemical changes take place in their cytoplasm.

The changes in shape and the chemical reactions enable the cell to carry out its special function. Red blood cells and **root hair** cells are just two examples of specialised cells. Figure 1.16 shows a variety of specialised cells.

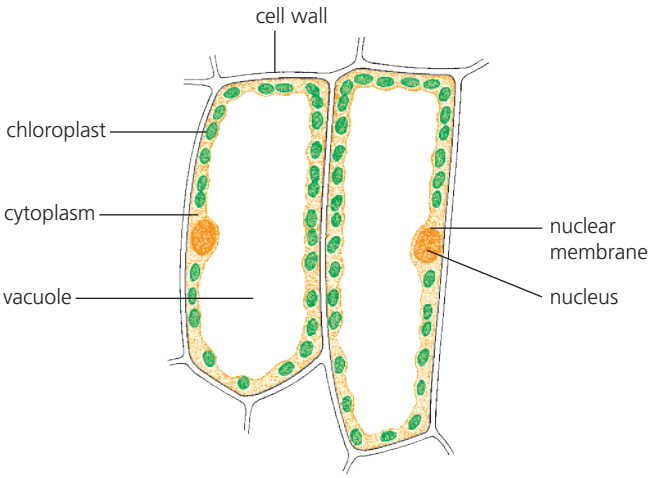
The specialisation of cells to carry out special functions in an organism is sometimes called 'division of labour' within the organism. Similarly, the special functions of mitochondria, ribosomes and other cell organelles may be called division of labour within the cell.



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

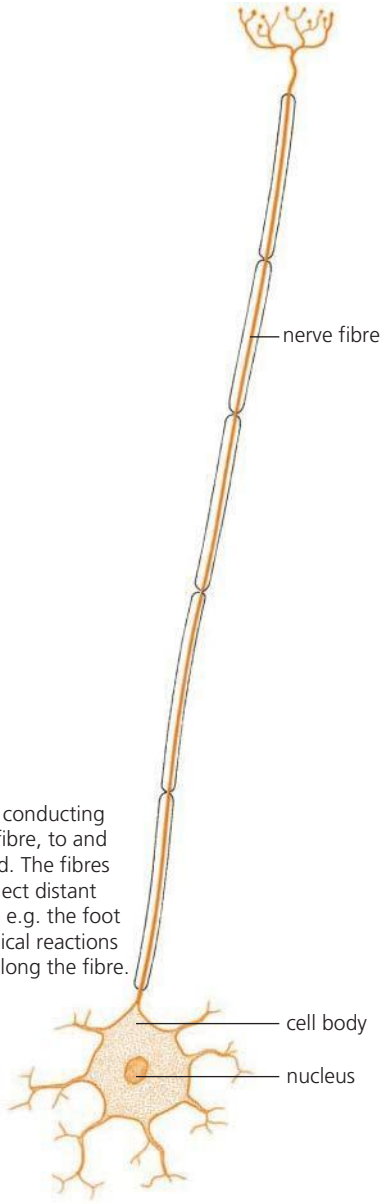


(b) root hair cell
These cells absorb water and mineral salts from the soil. The hair-like projection on each cell penetrates between the soil particles and offers a large absorbing surface. The cell membrane is able to control which dissolved substances enter the cell.

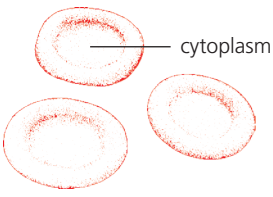


(c) palisade mesophyll cells
These are found underneath the upper epidermis of plant leaves. They are columnar (quite long) and packed with chloroplasts to trap light energy. Their function is to make food for the plant by photosynthesis using carbon dioxide, water and light energy.

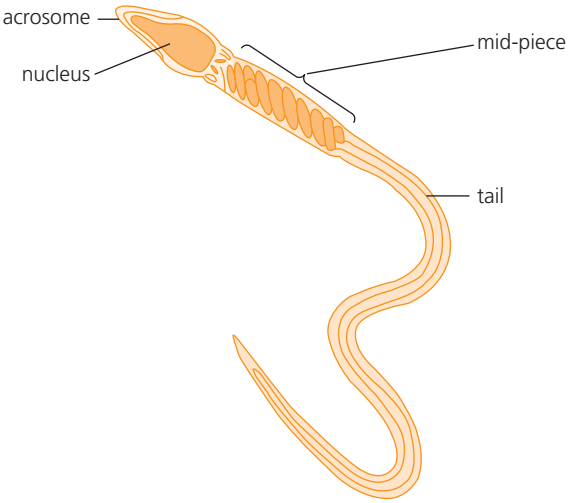
▲ **Figure 1.16** Specialised cells (not to scale)



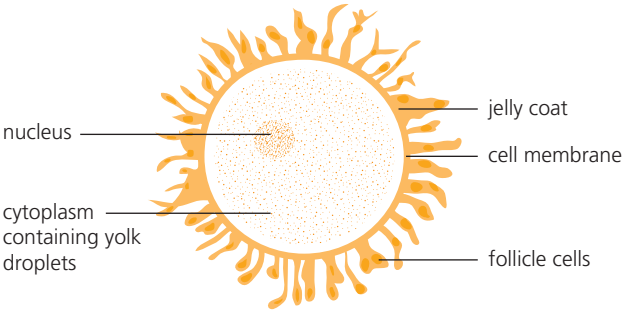
(d) nerve cells
These cells are specialised for conducting electrical impulses along the fibre, to and from the brain and spinal cord. The fibres are often very long and connect distant parts of the body to the CNS, e.g. the foot and the spinal column. Chemical reactions cause the impulses to travel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



(e) red blood cells
These cells are distinctive because they have no nucleus when mature. They are tiny disc-like cells that contain a red pigment called haemoglobin. This readily combines with oxygen and their function is the transportation of oxygen around the body.



(f) sperm cell
Sperm cells are male sex cells. The front of the cell is oval shaped and contains a nucleus which carries genetic information. There is a tip, called an **acrosome**, which secretes enzymes to digest the cells around an egg and the egg membrane. Behind this is a mid-piece which is packed with mitochondria to provide energy for **movement.** The tail moves with a whip-like action, enabling the sperm to swim. Their function is reproduction, achieved by fertilising an **egg cell.**



(g) egg cell
Egg cells are larger than sperm cells and are spherical. They have a large amount of cytoplasm, containing yolk droplets made up of protein and fat. The nucleus carries genetic information. The function of the egg cell is reproduction.

▲ **Figure 1.16** Specialised cells (not to scale) (continued)

Test yourself

10 In what way does the red blood cell shown in Figure 1.16(e) differ from most other animal cells?
11 Why does the cell shown in Figure 1.7(b) on page 4 appear to have no nucleus?

Tissues, organs, organ systems and the organism

FOCUS POINTS

★ Definitions of tissues, organs, organ systems and organism

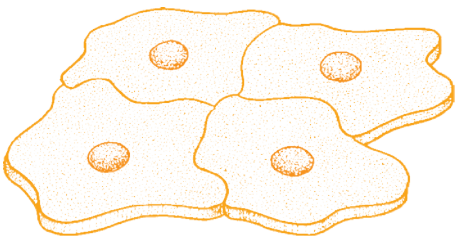
Some microscopic organisms are made of one cell only (see 'Features of organisms' in Chapter 2). These can carry out all the processes needed to keep them alive. The cells of the larger plants and animals cannot survive on their own. A muscle cell could not obtain its own food and oxygen. Other specialised cells provide the food and oxygen needed for the muscle cell to live. Unless these cells are grouped together in large numbers and made to work together, they cannot stay alive.

Tissues

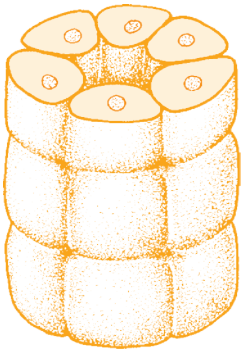
A tissue, like bone, nerve or muscle in animals, and **epidermis**, **xylem** or pith in plants, is made up of large numbers of cells. These are often just a single type. The cells of each type have a similar structure and function so that the tissue itself has a special function. For example, muscles contract to cause movement, xylem carries water in plants. Figure 1.17 shows how some cells are arranged to form simple tissues. Some forms of tissues are **epithelium**, tubes, sheets and **glands**.

Key definitions

A **tissue** is a group of cells with similar structures working together to perform a shared function.

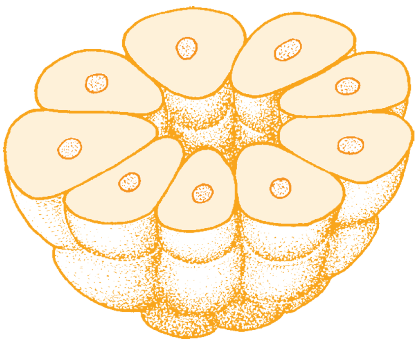


(a) cells forming an epithelium
A thin layer of tissue, e.g. the lining of the mouth cavity. Different types of epithelium form the internal lining of the windpipe, air passages, food canal, etc., and protect these organs from physical or chemical damage.



(b) cells forming a small tube
E.g. a kidney tubule (see page 210). Tubules such as this carry liquids from one part of an organ to another.

(c) one kind of muscle cell
Forms a sheet of muscle tissue. Blood vessels, nerve fibres and connective tissues will also be present. Contractions of this kind of muscle help to move food along the food canal or close down small blood vessels.



(d) cells forming part of a gland
The cells make chemicals, which are released into the central space and carried away by a tubule such as that shown in **(b)**. Hundreds of cell groups like this would form a gland like the salivary gland.

▲ **Figure 1.17** How cells form tissues

Organs

Organs are made of several tissues grouped together to make a structure with a special job. For example, the stomach is an organ that contains tissues made from epithelial cells, gland cells and muscle cells. These cells are supplied with food and oxygen brought by blood vessels. The stomach also has a nerve supply. The heart, **lungs**, intestines, brain and eyes are further examples of organs in animals. In flowering plants, the root, stem and leaves are the organs. Some of the tissues of the leaf are epidermis, palisade tissue, spongy tissue, xylem and **phloem** (see Chapter 6).

Key definitions

An **organ** is a structure made up of a group of tissues working together to perform a specific function.

Test yourself

12 **a** Study Figure 7.11 on page 106 and identify examples of tissues and an organ.

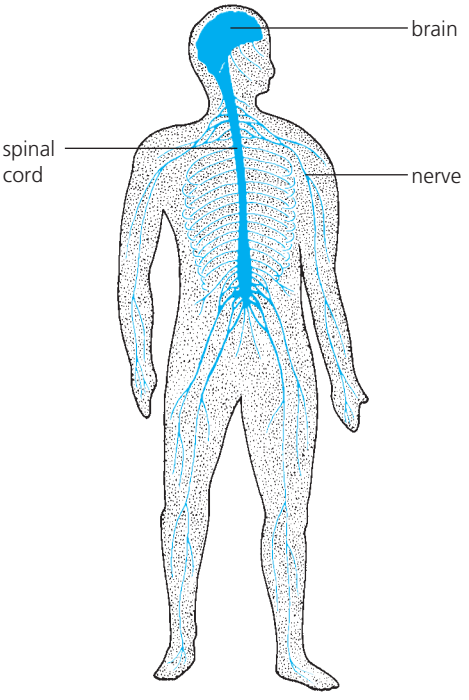
b Study Figure 8.14 on page 128 and identify examples of tissues and an organ.

Organ systems

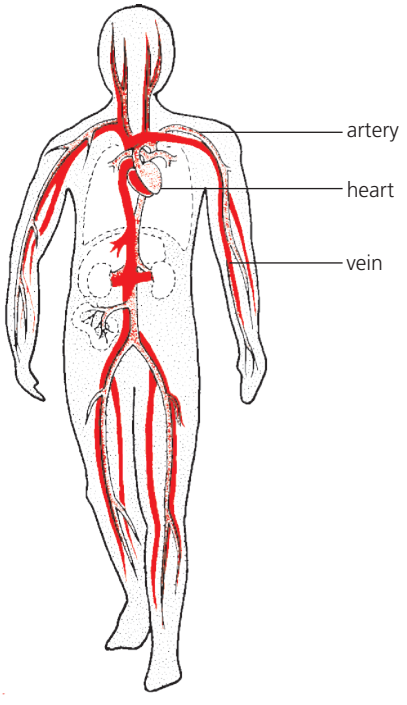
An **organ system** usually describes a group of organs with closely related functions. For example, the heart and blood vessels make up the **circulatory system**; the brain, spinal cord and nerves make up the **nervous system** (Figure 1.18). In a flowering plant, the stem, leaves and buds make up a system called the shoot (Figure 7.5 on page 103).

Key definitions

An **organ system** is a group of organs with related functions working together to perform a body function.



(a) nervous system



(b) circulatory system

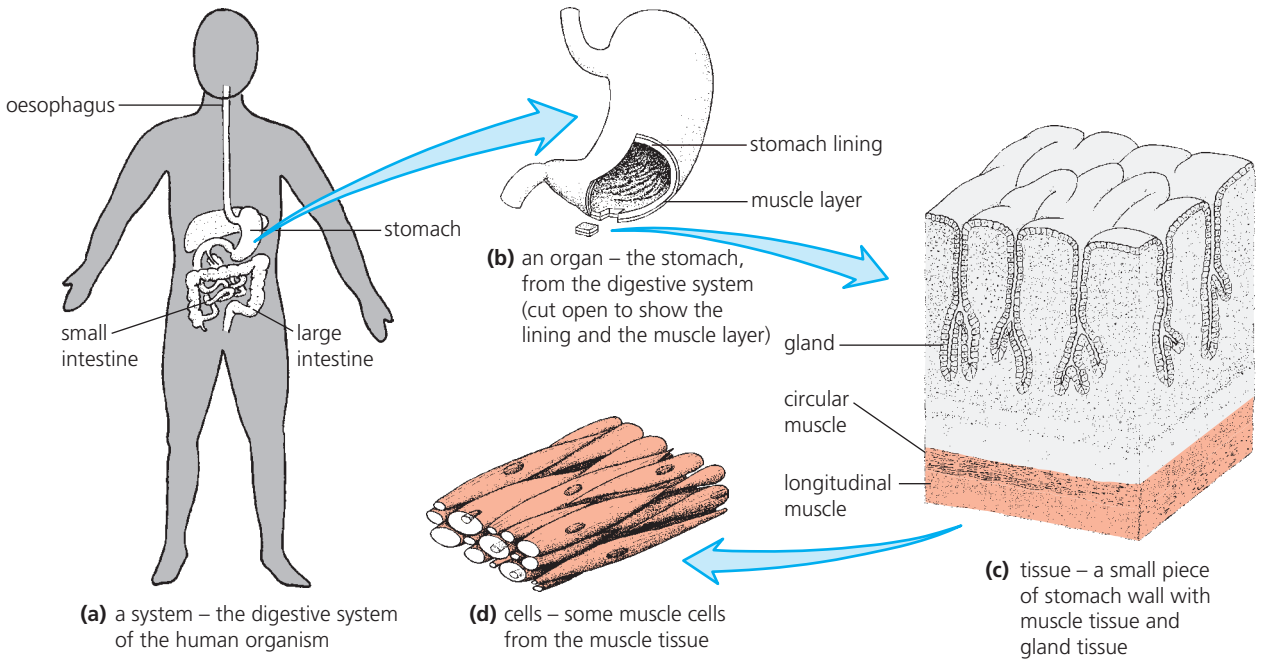
▲ **Figure 1.18** Two examples of systems in the human body

Organisms

Key definitions

An **organism** is an individual animal or plant, formed by all the organs and systems working together to produce an independent living thing.

An example in the human body of how cells, tissues and organs are related is shown in Figure 1.19.



▲ **Figure 1.19** An example of how cells, tissue and organs are related

Size of specimens

FOCUS POINTS

- ★ How do you calculate the magnification and size of biological specimens using millimetres as units?
- ★ How do you convert measurements between millimetres and micrometres?

The light microscope

You cannot see most cells with the naked eye. A hand lens has a **magnification** of up to ×20, but this is not enough to see the detail in cells. The light microscope (Figure 1.20) has two convex lenses, with magnifications of up to ×1 500, although most found in school laboratories only magnify to ×400. The eyepiece lens is usually ×10 and there is a choice of objective lenses (usually ×4, ×10 and ×40), set in a nosepiece which can be rotated (turned round). Light, from a mirror or a bulb, is projected through the specimen placed on a microscope slide. The light passes through the objective and eyepiece lenses, magnifying the image so you can see detail of the specimen. You can use coarse and fine focus knobs to make the image clearer. You need to place specimens on microscope slides, which may be temporary or permanent preparations. You can prepare temporary slides quickly, but the specimens dry out quite rapidly, so they do not store well. You carefully lay a cover-slip (a thin piece of glass) over the specimen. This helps to keep it in place, slows down dehydration and protects the objective lens from moisture or stains. To make a permanent preparation you usually need to dehydrate the specimen and fix it in a special resin, for example, Canada Balsam. These types of slides store well for a long time.

Practical work

Safety

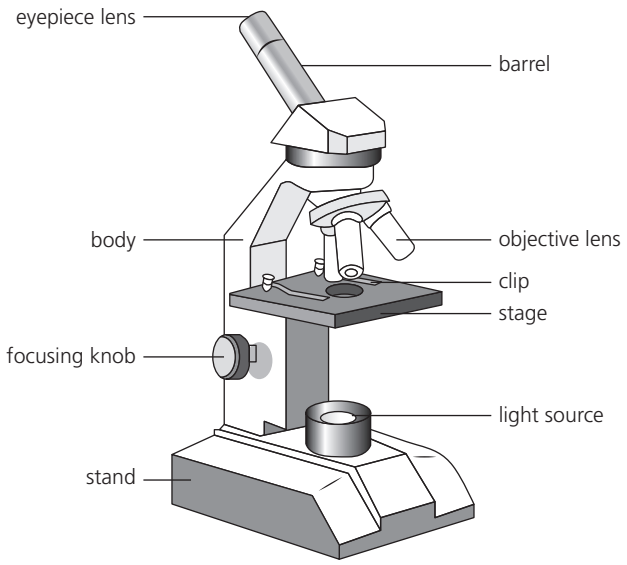
- Do not use direct sunlight as a light source.

Using a microscope

- If the microscope has its own light source, plug the microscope in and switch it on.
- Arrange the microscope so that the body is nearest to you.
- If the microscope has a mirror, switch on a bench lamp and adjust the mirror to reflect the light into the microscope.
- Turn the nosepiece so that the lowest power objective lens (e.g. ×4) is in line with the barrel.
- Place a slide on the stage and use the clips to secure it. Line up the specimen so that it lying directly over the hole in the centre of the stage.
- Look down the eyepiece and adjust the light source so that maximum amount of light is passing through the microscope. There may be a diaphragm (a rotating disc) under the stage that also needs adjusting.
- Gently turn the focusing knob until the specimen becomes focused.
- To increase the magnification, turn the nosepiece to select the next objective lens (e.g. ×10) and adjust the focus.
- Repeat the process if the highest magnification (e.g. ×40) is required.

Calculating magnification

A lens is usually marked with its magnifying power. This tells you how much larger the image will be compared to the specimen's **actual size**. So, if the lens is marked ×10, you know that the image will be ten times greater than the specimen's real size. Since a light microscope has two lenses, you need to know the magnification of both lenses. For example, if the specimen is viewed using a ×10 eyepiece lens and ×40 objective lens, the total magnification will be 10 × 40 = 400.



▲ **Figure 1.20** A light microscope

Key definitions

Magnification is the observed size of an image divided by the actual size of the specimen.

When you draw the image, your drawing is usually much larger than the image, so the total magnification of the specimen is even bigger.

$$\text{Magnification} = \frac{\text{image size}}{\text{actual size of the specimen}}$$

When doing this type of calculation, you need to make sure that the units of both sizes are the same. If they are different, convert one to make them the same. For example, if the actual size is in **millimetres** and the **image size** is in centimetres, convert the centimetres to millimetres. (There are 10 millimetres in a centimetre.)

In questions, you may be asked to calculate the actual size of a specimen, given a drawing or photomicrograph and a magnification.

$$\text{Actual size of the specimen} = \frac{\text{image size}}{\text{magnification}}$$

When you give the answer, make sure you quote the units (which will be the same as those used for measuring the observed size).

Test yourself

13 a In order to see cells clearly in a section of plant tissue, which magnification would you have to use?

A ×5 **C** ×100
B ×10 **D** ×1 000

b What is the approximate width (in millimetres) of one of the largest cells in Figure 1.3?

14 In Figure 1.3, the cell membranes are not always clear. Why is it still possible to decide roughly how many cells there are in each tubule section?

Worked example

If you are asked to calculate the magnification of a drawing, e.g. of a cell, you will be told the actual size of the cell and the diameter of the cell in the drawing.

Start by making sure that both figures (the observed size and actual size) are the same units. For example, if the drawing of a cell is 6 cm wide (the **observed size**) and its **actual size** is 0.1 mm you need to change the cm to mm.

There are 10 mm in 1 cm, so 6 × 10 = 60 mm.

Now use these figures in the equation:

$$\text{Magnification} = \frac{\text{image size}}{\text{actual size of the specimen}}$$

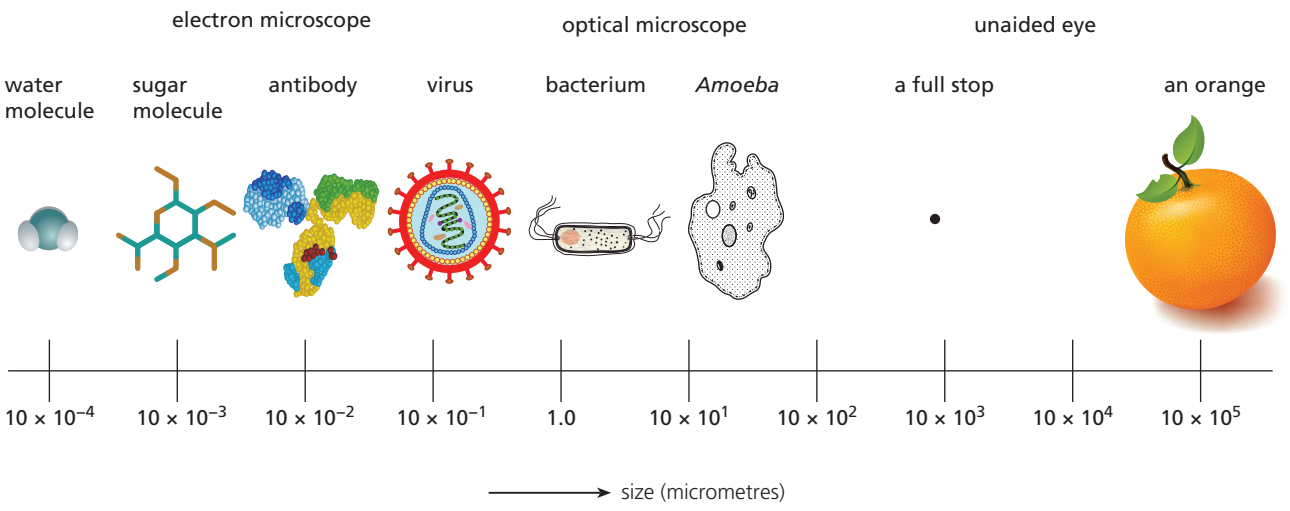
$$\text{Magnification} = \frac{60}{0.1} = \times 600$$

Tasks

1 The image of a root hair cell is 5.0 cm long. Its actual size is 1.5 mm. Calculate the magnification of the image.
2 One of the moss leaf cells in the photomicrograph in Figure 1.14 is 2.5 cm wide.
The magnification of the image is ×500. Calculate the actual size of the cell.
3 The diameter of a drawing of a red blood cell is 14 mm.
The actual size of the cell is 7 µm. Calculate the magnification of the image.

Converting measurements

Organelles in cells are too small to be measured in millimetres. A smaller unit, called the **micrometre** (micron or µm), is used. Figure 1.21 shows a comparison of the sizes of a range of objects.



▲ **Figure 1.21** Comparing the sizes of a range of objects

There are:

- 1 000 000 micrometres in a metre
- 10 000 micrometres in a centimetre
- 1 000 micrometres in a millimetre.

Remember to make sure that the units of both sizes used in a calculation involving magnification are the same. So, if the actual size is in micrometres and the observed size is in millimetres, convert the millimetres to micrometres.

Test yourself

15 The tail of a sperm cell is 0.05 mm long. What is its length in micrometres?

16 An amoeba is 750 μm long. Calculate its length in centimetres.

Revision checklist

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

- ✔ The definitions of cell, tissue, organ, system and organism.
- ✔ Nearly all plants and animals are made up of microscopic cells.
- ✔ All cells contain cytoplasm surrounded by a cell membrane.
- ✔ Most cells have a nucleus.
- ✔ Many chemical reactions take place in the cytoplasm to keep the cell alive.
- ✔ Cytoplasm contains organelles, which include mitochondria (respiration), chloroplasts (photosynthesis) and ribosomes (protein synthesis).
- ✔ The nucleus directs the chemical reactions in the cell and also controls cell division.
- ✔ Plant cells have a cellulose cell wall and a large central vacuole.
- ✔ Cells are often specialised in their shape and activity to carry out special jobs.
- ✔ Large numbers of similar cells packed together form a tissue.
- ✔ Different tissues arranged together form organs.
- ✔ A group of related organs makes up an organ system.
- ✔ The magnification of a specimen can be calculated if the actual size and the size of the image are known.

$$\text{Magnification} = \frac{\text{image size}}{\text{actual size of the specimen}}$$

Exam-style questions

1 The terms tissue, organ and organ systems are used when describing the organisation inside an organism.
Complete the table by
a defining what each term means [3]
b giving one example in a plant and one in an animal for each structure. [6]

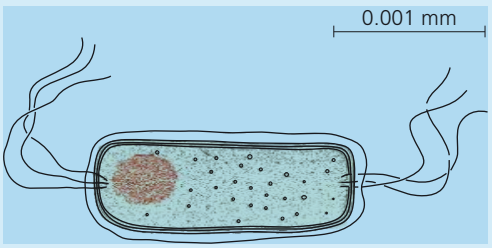
name of structure	definition	example in a plant	example in an animal
tissue			
organ			
organ system			

2 **a** Complete the table to compare the parts present in a liver cell with those in a palisade cell. One component has been done for you. [5]

part of cell	present in palisade cell	present in liver cell
nucleus	✓	✓
cell wall		
chloroplast		
cytoplasm		
membrane		
(sap) vacuole		

b Choose **three** of the parts and state their functions. [3]

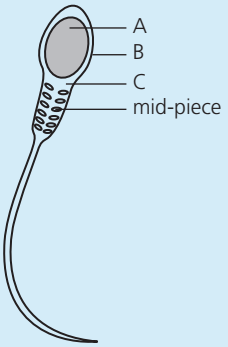
3 The diagram shows a drawing of a bacterium.



a Label **four** parts of the cell. [4]
b Calculate the magnification of the drawing. [2]

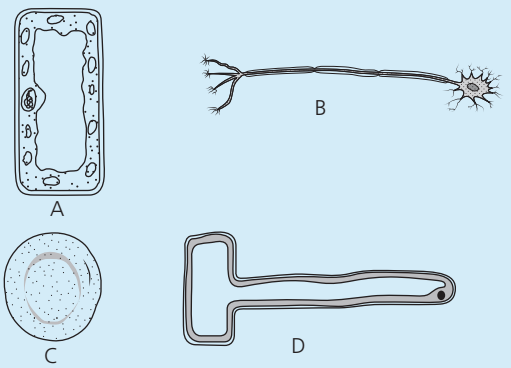
4 **a** Draw a labelled diagram of a named specialised plant cell. [5]
b Describe the function of the cell. [1]

5 The diagram shows a human sperm cell.



a State the names of parts A, B and C. [3]
b The mid-piece of the sperm cell provides energy for the cell. Suggest what type of organelle it contains. [1]
c State the function of the sperm cell. [1]

6 The diagram shows four specialised cells.



a Complete the table, using the letters of the cells to identify them as plant or animal cells. [1]

	plant	animal
letters		

b State **two** features found in all plant cells but not in animal cells. [2]
c State **one** function of each of cells A, B, C and D. [4]

7 A student used a microscope to study a human cheek cell. She drew the cell. The drawing was 30 mm wide. The actual diameter of the cell was 60 µm.
a Calculate the magnification of the drawing. [3]
b The eyepiece of the microscope was ×10 and its objective lens was ×40. Calculate the total magnification of the microscope. [1]

2 Classification

Focus

In the last chapter, you were introduced to the main features of animal, plant and bacterial cells and their functions. You studied examples of a range of specialised cells and how they are adapted to carry out their roles. You learned about the levels of organisation within the organism and how to calculate the magnification of microscopic structures. In this chapter you will be shown why it is necessary to classify organisms (there are 8.7 million species). You will learn about why biologists use the internationally agreed system to organise organisms into groups and the main features used to place animals and plants into the appropriate kingdoms and subgroups. Can you name many of the plants and animals you see around you? Do you know any of their scientific names or the groups they belong to?

Classification systems

FOCUS POINTS

- ★ How are organisms classified?
- ★ What is a species?
- ★ What is the binomial system?
- ★ How do you make a dichotomous key?
- ★ How do classification systems reflect evolutionary relationships?
- ★ How is DNA used for classifying organisms?
- ★ Why do closely related organisms have more similar base sequences than those that share more distant ancestors?

Key definitions

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

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

There are millions of different organisms living on the Earth. Biologists sort them into a meaningful order, they **classify** them.

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

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

Species

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

Members of a species also often look very similar to each other in appearance, Common mynas, eagles and parrots are three different species of bird. Apart from small **variations**, members of a species are almost identical in their anatomy, physiology and behaviour. Animals may look quite different if humans have been involved in their breeding programmes. For example, all cats belong to the same species, but there are wide variations in the appearance of different breeds (see 'Variation' in Chapter 17). An American Longhair and a Siamese (Figure 17.30) may look very different but they breed together successfully.

Closely related species are grouped into a **genus** (plural: **genera**). For example, there are 45 species of bronzeback snake, all in the same genus *Dendrelaphis*.

Binomial nomenclature

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

'Money Plant' and 'Devil's Ivy' are two common names for the same wild plant. If you are not aware that these are alternative names this could lead to confusion. If the botanical name, *Epipremnum aureum*, is used there is no chance of error. The Latin form of the name allows it to be used in all the countries of the world regardless of language barriers.

People living in the Indian subcontinent are familiar with the appearance of a robin. The male is mainly black, with some red–brown bottom feathers (although some more northern **populations** are more brown than black). Males also have a white flash across their shoulder. The female has completely brown upper feathers and grey–brown underparts. Its scientific name is *Copsychus fulicatus* and the adult is about 17 cm long (see Figure 2.1). However, someone living in Britain would describe a robin very differently. It has the species name *Erithacus rubecula*, and is very distinctive. It has a round body with a bright orange–red breast, a white belly and olive–brown upper feathers. It is only 14 cm long (see Figure 2.2). A British scientist could get very confused talking to an Indian scientist about a robin! Again, the use of the scientific name avoids any confusion.

The binomial system of naming species is an internationally agreed system in which the scientific name of an organism is made up of two parts, showing the genus and the species. Binomial means 'two names'; the first name gives the genus and the second gives the species. For example, the Egyptian mongoose and Indian grey mongoose are both in the genus *Herpestes* but they are different species; the Egyptian mongoose is *Herpestes ichneumon* and the Indian grey mongoose is *Herpestes edwardsii*.

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

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

▲ **Figure 2.1** Indian robin, *Copsychus fulicatus* ♂

▲ **Figure 2.2** British robin, *Erithacus rubecula* ♂

Test yourself

1 Explain the meaning of the term *binomial system*. Give an example in your answer.

Dichotomous keys

We use **dichotomous keys** to identify unfamiliar organisms. Keys simplify the process of identification. Each key is made up of pairs of contrasting features (dichotomous means two branches), starting with quite general

characteristics and moving on to more specific ones. When we follow the key and make suitable choices it is possible to identify the organism correctly.

Figure 2.3 shows an example of a dichotomous key that could be used to place an unknown **vertebrate** in the correct class. Item 1 gives you a choice between two alternatives. If the animal is cold-blooded, you move to item 2 and make a further choice. If it is warm-blooded, you move to item 4 for your next choice.

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

VERTEBRATE CLASSES

1	Cold-blooded	2
	Warm-blooded	4
2	Has fins but no limbs	**Fish**
	Has four limbs	3
3	Has no scales on body	**Amphibian**
	Has scales	**Reptile**
4	Has feathers	**Bird**
	Has fur	**Mammal**

▲ **Figure 2.3** A dichotomous key for vertebrate classes

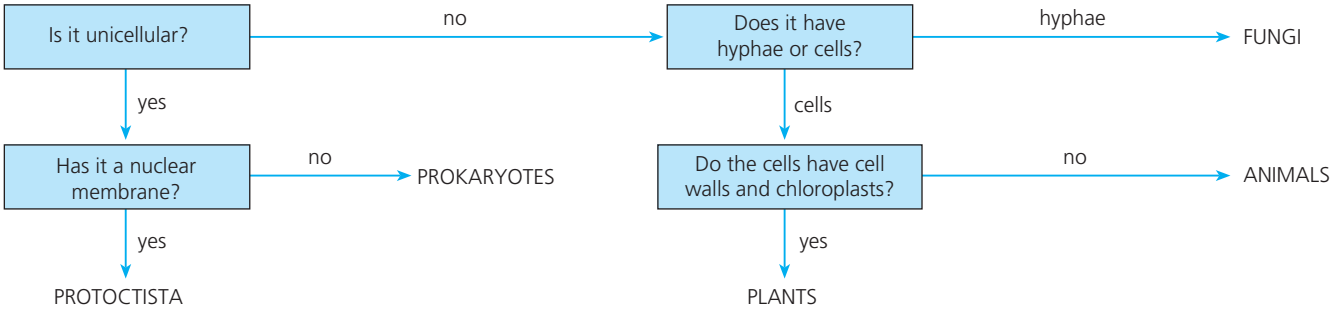
Figure 2.4 is a key for identifying some of the possible invertebrates to be found in a compost heap. Of course, you do not need a key to identify these familiar animals, but it does show you how a key can be constructed.

INHABITANTS OF A COMPOST HEAP

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

▲ **Figure 2.4** A dichotomous key for some invertebrates in a compost heap

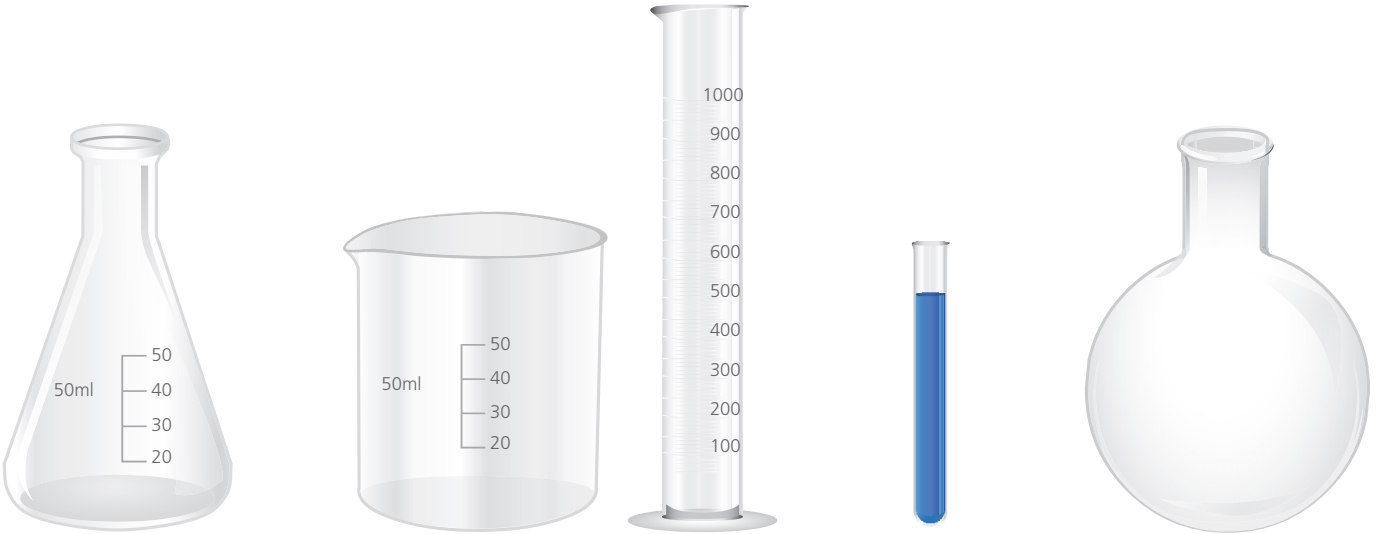
You need to be able to develop the skills to make simple dichotomous keys, based on easily identifiable features. If you know the main characteristics of a group, it is possible to draw up a logical plan for identifying an unfamiliar organism. One such plan is shown in Figure 2.5.



▲ **Figure 2.5** Identification plan

Figure 2.6 shows five different items of laboratory glassware. If you were unfamiliar with the resources in a science laboratory you may not be able to name them. We are going to design a dichotomous key to help with identification. All the items have one thing in common – they are made of glass. However, each has features that make it distinctive and we can write questions based on these features.

First you need to study the items, to work out what some of them have in common and what makes them different from others. For example, some have a pouring spout, others have graduations marked on the glass for measuring, some have a neck (where the glass narrows to form a thinner structure), some can stand without support because they have a flat base, and so on.



▲ **Figure 2.6** Items of laboratory glassware

The first question should be based on a feature that will split the group into two. The question is going to give a 'yes' or 'no' answer. For each of the two subgroups formed, a further question based on the features of some of that sub-group should then be written. Figure 2.7 shows one possible solution.

1 Has it got a pouring spout?

Yes 2

No 3

2 Has it got a broad base?

Yes ..... **Beaker**

No ..... **Measuring cylinder**

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

Yes ..... **Boiling tube**

No 4

4 Has it got sloping sides?

Yes ..... **Conical flask**

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

▲ **Figure 2.7** Dichotomous key for identifying laboratory glassware

Test yourself

2 The animals **X** and **Y** shown in Figure 2.8 are found in a compost heap. Use the key in Figure 2.4 to identify them.

▲ **Figure 2.8** Two invertebrates found in a compost heap

3 The example in Figure 2.7 is not the only way that a dichotomous key could be set up for the laboratory glassware shown. Make your own key and test it for each object.

Going further

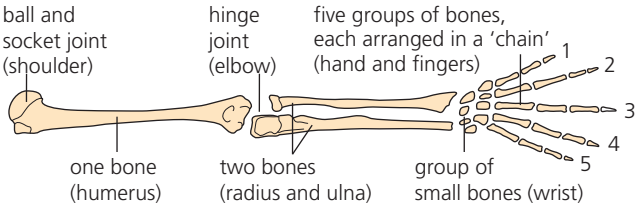
Classification and evolutionary relationships

Scientists make it possible to understand evolutionary relationships when they classify organisms. Vertebrates all have the presence of a vertebral column, along with a skull protecting a brain and a pair of jaws (usually with teeth). Studying the anatomy of different groups of vertebrates helps us to learn about their **evolution**.

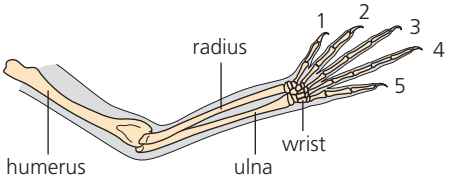
The skeletons of the front limb of five types of vertebrate are shown in Figure 2.9. Although the limbs have different functions, such as holding on to objects, flying, running and swimming, the arrangement and number of the bones is almost the same in all five. There is a single top bone (the humerus), with a ball and socket joint at one end and a hinge joint at the other. It makes a joint with two other bones (the radius and ulna) that join to a group of small wrist bones. The limb skeleton ends with five groups of bones (the hand and fingers), although some of these groups are missing in the bird.

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

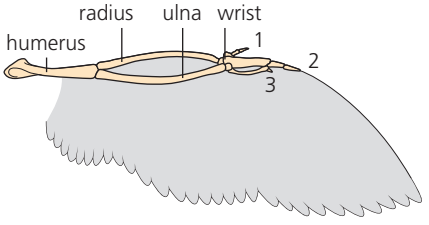
Pangolins and armadillos (Figure 2.10) may look very closely related, but appearances can be misleading. At one stage scientists placed them in the same group together with anteaters, but we now know that some species have evolved similar characteristics completely independently and have no close links at all.



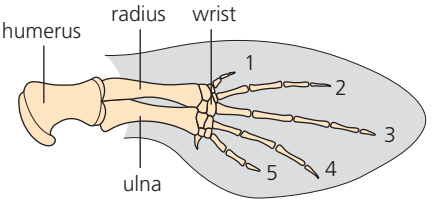
(a) pattern of bones in human forelimb



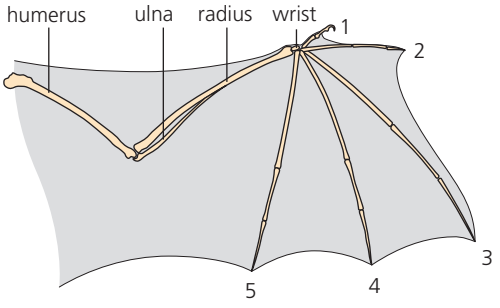
(b) lizard



(c) bird



(d) whale



(e) bat

▲ **Figure 2.9** Skeletons of a limb of five different vertebrates

▲ **Figure 2.10** Pangolin (top) and armadillo (bottom)

▲ **Figure 2.11** Pangolin body scales (top) and armadillo bony plates (bottom)

If organisms share a common ancestor this will be reflected in how they are classified. However, if they are found not to share a common ancestor, as is the case with the pangolin and armadillo, their classification will be different. Although at first glance the pangolin and armadillo may appear to share a common ancestor, a closer study of the two species reveals major differences. The pangolin has a body covered in scales made of keratin (the same material as our nails), as shown in Figure 2.11. It has no teeth but uses its long tongue to feed on ants and termites. It can roll into a tight ball for protection. The armadillo has an armoured body covering, made up of hard bony plates (see Figure 2.11). It has long claws which it uses for digging and making a burrow. Also, it has small teeth, which are not covered in **enamel**, and feeds on grubs and insects. Some armadillo species can roll up into a ball when threatened by predators. The two animals are both mammals but the differences between them mean that they are not classified in the same group.

Use of DNA sequencing in classification

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

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

However, genetic evidence using DNA provides a different understanding – humans are more closely related to chimpanzees (1.2% difference in the **genome** – the complete set of genetic material of the organism) and gorillas (1.6% different) than to orang-utans (3.1% different). Also, chimpanzees are closer to humans than to gorillas (see Figure 2.12).

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

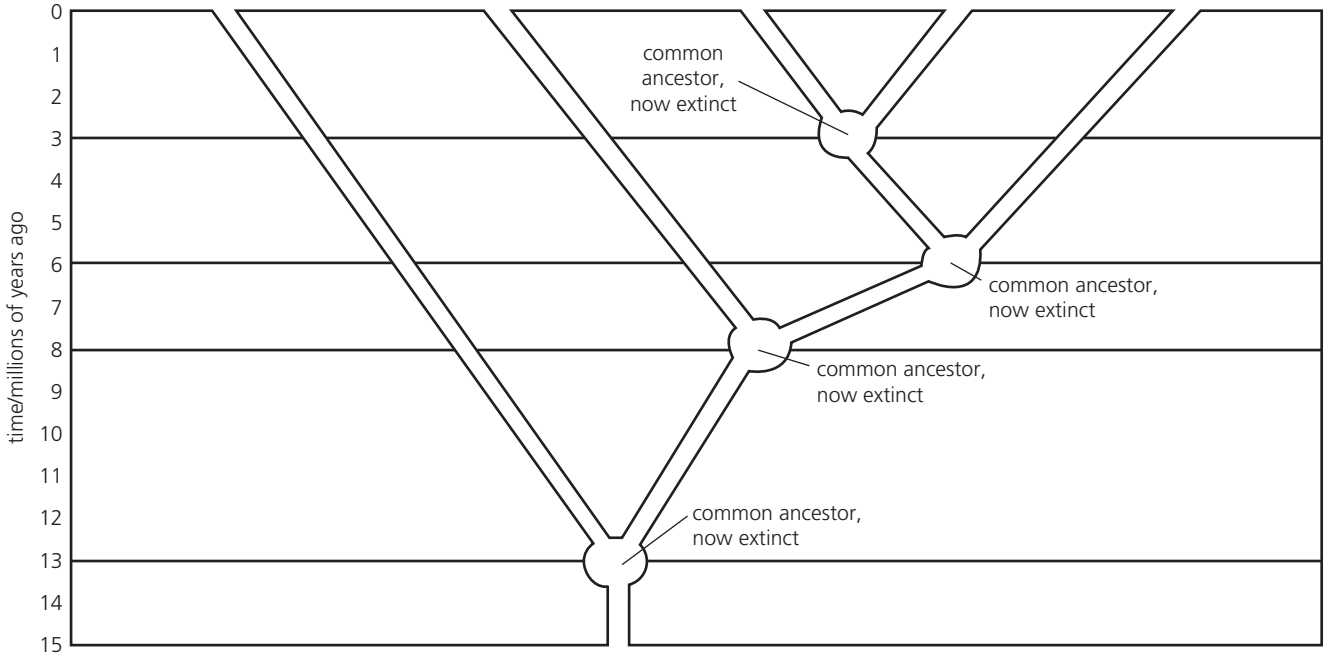
Orang-utan
48 chromosomes

Gorilla
48 chromosomes

Chimpanzee
48 chromosomes

Bonobo
48 chromosomes

Human
46 chromosomes



▲ **Figure 2.12** Classification of primates based on DNA evidence

Features of organisms

FOCUS POINTS

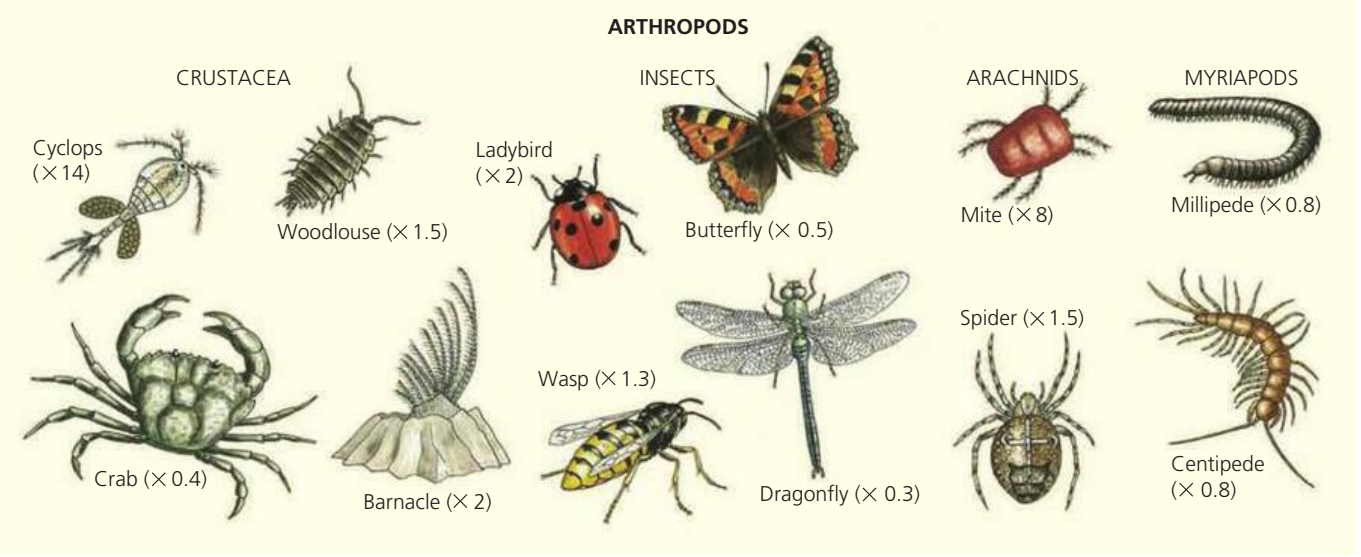
- ★ What are the main features used to place animals and plants into the appropriate kingdoms?
- ★ What are the main features used to place organisms into groups in the animal kingdom?
- ★ How do you classify organisms using their features?
- ★ What are the main features used to place all organisms into one of the five kingdoms?
- ★ What are the main features used to place organisms into groups in the plant kingdom?
- ★ What are the main features of viruses?

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

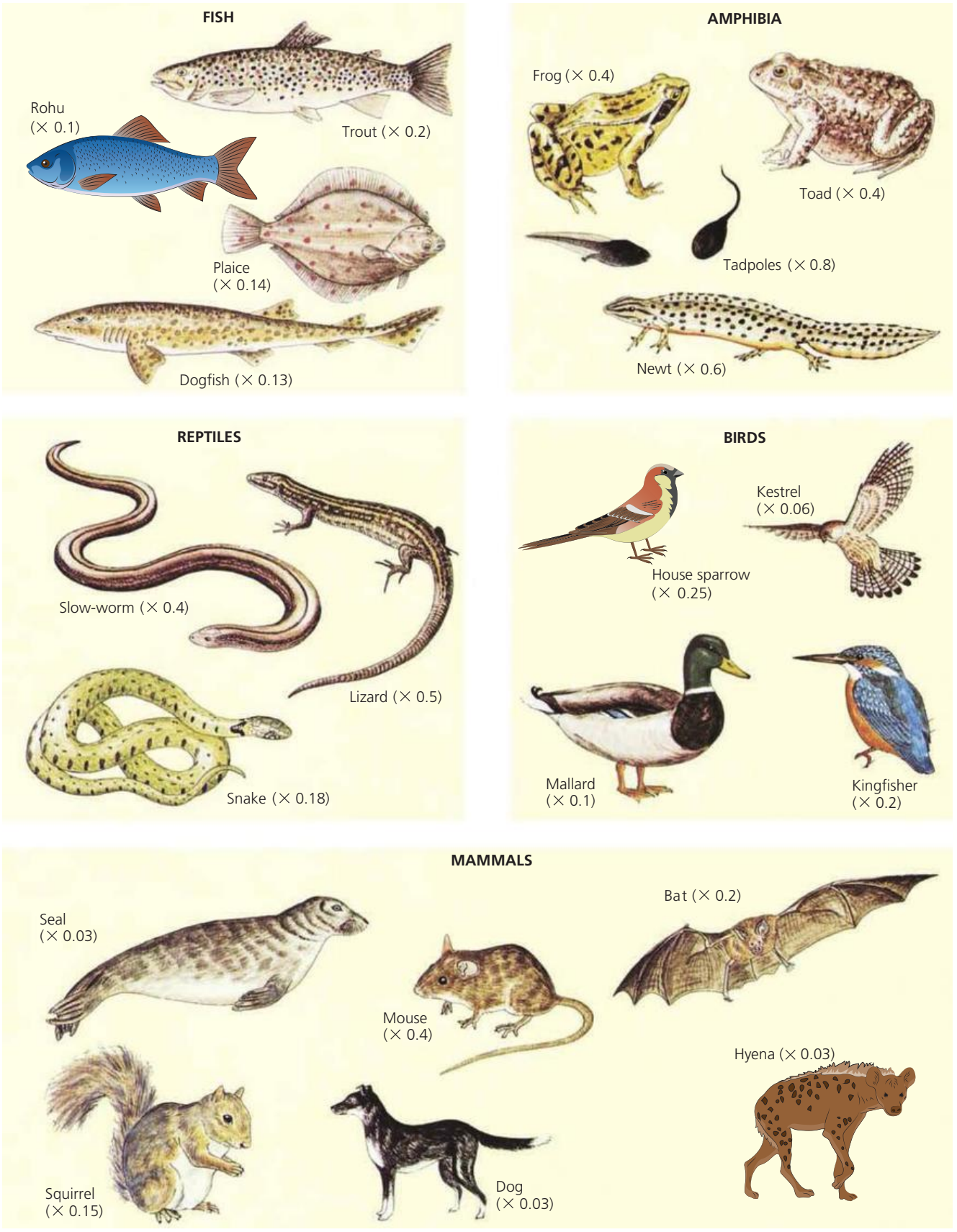
A **kingdom** is a category of living organisms.

The animal kingdom

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



▲ **Figure 2.13** The animal kingdom; examples of arthropods – one of the invertebrate groups (phyla)



▲ **Figure 2.14** The animal kingdom; the vertebrate classes

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

* **Arthropods**
- CLASS
- Crustacea (crabs, shrimps, water fleas)
- Insects
- Arachnids (spiders and mites)
- Myriapods (centipedes and millipedes)

Vertebrates
- CLASS
- Fish
- Amphibia (frogs, toads, newts)
- Reptiles (lizards, snakes, turtles)
- Birds
- Mammals

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

Arthropods

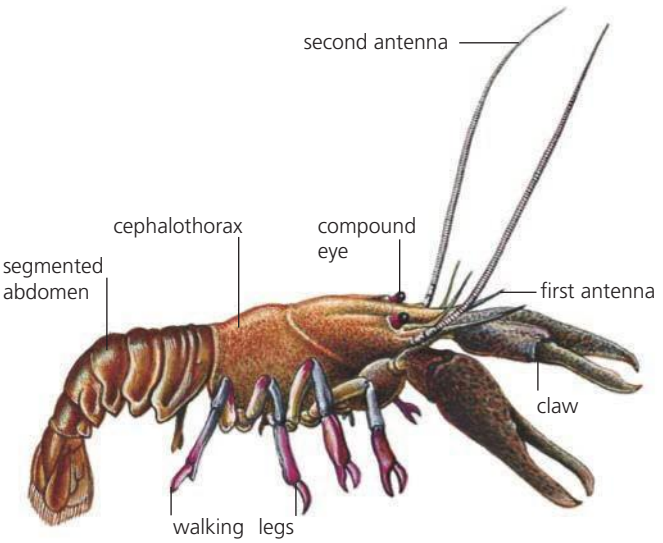
The arthropods include the crustacea, insects, centipedes and spiders (see Figure 2.13). The name arthropod means 'jointed limbs', and this is a feature common to them all. They also have a hard, firm, external skeleton, called a **cuticle**, which encloses their bodies. Their bodies are segmented (made up of several sections), and, between the segments (sections), there are flexible joints which allow movement. In most arthropods, the segments are grouped together to form distinct regions, the head, thorax (the middle section of the body) and abdomen (the part of the body behind the thorax). Table 2.1 on page 30 outlines the key features of the four classes of arthropod.

Crustacea

Marine crustacea are crabs, prawns, lobsters, shrimps and barnacles. Freshwater crustacea are water fleas, *Cyclops*, the freshwater shrimp (*Gammarus*) and the water louse (*Asellus*). Woodlice are land-dwelling crustacea. Some of these crustacea are shown in Figure 2.13.

Like all arthropods, crustacea have an exoskeleton (a rigid external skeleton) and jointed limbs. They also have two pairs of antennae (long thin feelers attached to the head) which are sensitive to touch and to chemicals, and they have compound eyes. Compound eyes are made up of tens or hundreds of separate **lenses** with light-sensitive cells underneath. They can form a simple image and are very sensitive to movement.

Most crustacea have a pair of jointed limbs on each segment of the body, but those on the head segments are modified to form antennae or specialised mouth parts for feeding (see Figure 2.15).

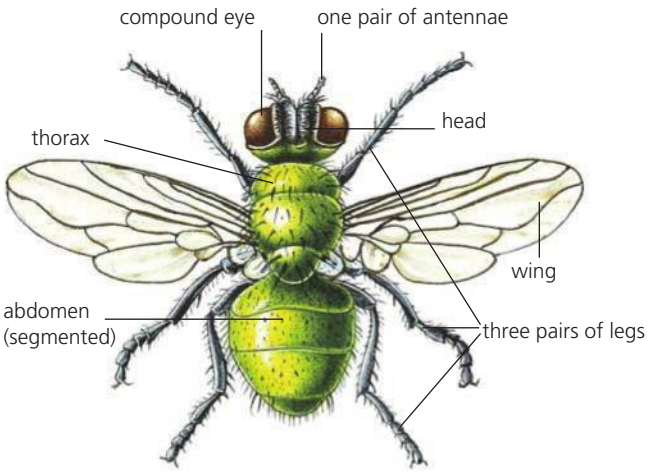


▲ **Figure 2.15** External features of a crustacean (lobster ×0.2)

Insects

The insects form a very large class of arthropods. Some are shown in Figure 2.13. Wasps, butterflies, mosquitoes, houseflies, earwigs (which you identified from Figure 2.8), greenflies (shown in Figure 2.16) and beetles (e.g. ladybird) are just a few of the subgroups in this class.

Insects have segmented bodies with a firm exoskeleton, three pairs of jointed legs, compound eyes and, usually, two pairs of wings. The segments are grouped into distinct head, thorax and abdomen regions (see Figure 2.16).



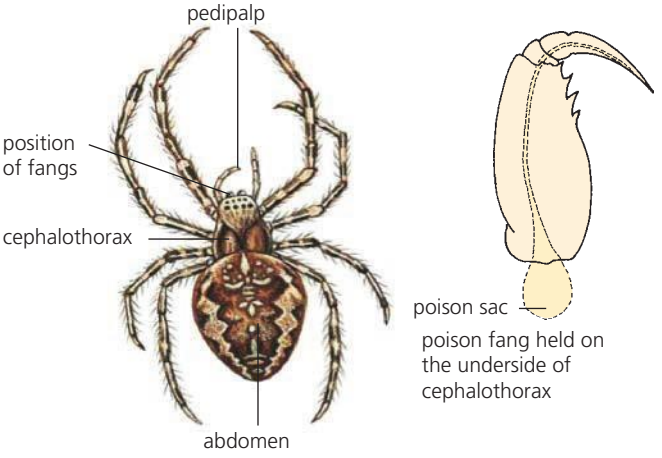
▲ **Figure 2.16** External features of an insect (greenbottle ×5). Flies, midges and mosquitoes have only one pair of wings

Insects are different from crustacea because they have wings, only one pair of antennae and only three pairs of legs. There are no limbs on the abdominal segments.

The insects have very successfully colonised the land. One reason for their success is that their cuticle stops water loss from inside the body and stops water entering the body. So the body of an insect is prevented from drying out even in very hot, dry climates. It can survive in these extreme conditions.

Arachnids

These are spiders, scorpions, mites and ticks. Their bodies are divided into two regions, a combined head and thorax region, called the cephalothorax, and the abdomen (see Figure 2.17). They have four pairs of limbs on their cephalothorax. In addition, there are two pairs of pedipalps. One pair is used in reproduction; the other is used to pierce their prey and paralyse it with a poison secreted by a gland at the base. There are usually several pairs of simple eyes.

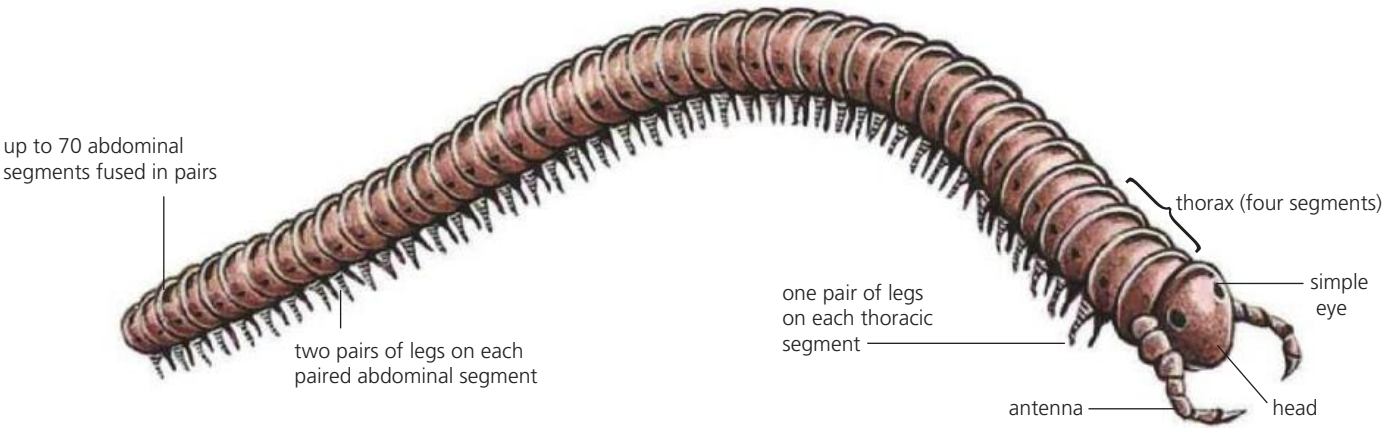


▲ **Figure 2.17** External features of an arachnid (×2.5)

Myriapods

These are millipedes and centipedes. They have a head and a segmented body that is not clearly divided into thorax and abdomen. There is a pair of legs on each body segment but in the millipede the abdominal segments are merged together in pairs and it looks as if it has two pairs of legs per segment (see Figure 2.18).

As the myriapod grows, extra segments are formed. The myriapods have one pair of antennae and simple eyes. Centipedes are **carnivores**, feeding on other animals, but millipedes are **herbivores**, feeding on plant material.



▲ **Figure 2.18** External features of a myriapod (×2.5)

▼ **Table 2.1** Key features of the four classes of arthropods

Insects	Arachnids	Crustacea	Myriapods
e.g. dragonfly, wasp	e.g. spider, mite	e.g. crab, woodlouse	e.g. centipede, millipede
• three pairs of legs	• four pairs of legs	• five or more pairs of limbs	• 10 or more pairs of legs (usually one pair per segment)
• body divided into head, thorax and abdomen	• body divided into cephalothorax and abdomen	• body divided into cephalothorax (combined head and thorax) and abdomen	• body not obviously divided into thorax and abdomen
• one pair of antennae	• no antennae	• two pairs of antennae	• one pair of antennae
• one pair of compound eyes	• several pairs of simple eyes	• one pair of compound eyes	• simple eyes
• usually have two pairs of wings	• pair of pedipalps adapted for biting and poisoning prey	• exoskeleton often forms a hard covering over most of the body	

Test yourself

4 What features do all arthropods have in common?

5 State two features for each of the arthropod classes (insects, crustaceans, arachnids and myriapods) that distinguishes it from the others.

Vertebrates

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

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

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

The five classes of vertebrates are fish, amphibia, reptiles, birds and mammals. Table 2.2 on page 33 summarises the key features of these classes.

Body temperature

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

Warm-blooded animals usually have a body temperature that is higher than their surroundings. The main difference, however, is that these temperatures are kept mainly constant despite any variation in external temperature. There are internal regulatory mechanisms (see Chapter 14) that keep the body temperature within narrow limits.

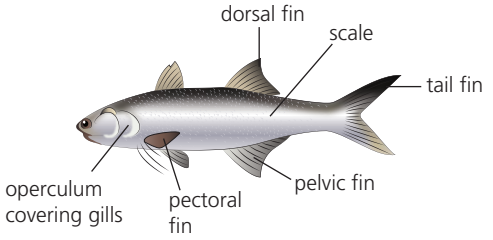
The advantage of being warm-blooded is that an animal's activity is not dependent on the surrounding temperature. A lizard's body movements may become slow if the surrounding temperature falls. This could be a disadvantage if the lizard is being chased by a warm-blooded predator whose speed and reactions are not affected by low temperatures.

Fish

Fish are cold-blooded vertebrates. Many of them have a smooth, streamlined shape that allows them to move through the water easily (see Figure 2.19). Their bodies are covered with overlapping scales and they have fins, which are important in movement.

Fish have filamentous gills to breathe. The gills are protected by a bony plate called the operculum.

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

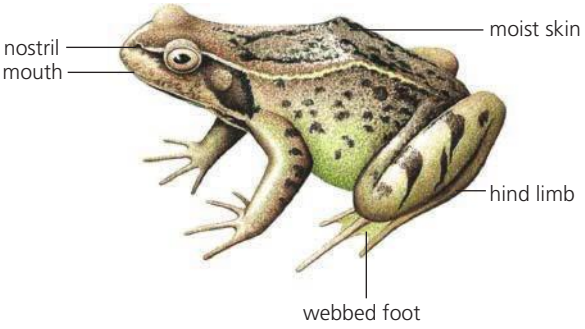


▲ **Figure 2.19** Rawas (*Eleutheronema* ×0.1)

Amphibia

Amphibia are cold-blooded vertebrates with four limbs and no scales. The class includes frogs, toads and newts. The name, amphibian, means 'double life' and refers to the fact that the organism spends part of its life in water and part on the land. Most frogs, toads and newts spend their life on the land where it is moist and return to water only to lay eggs.

The external features of the common frog are shown in Figure 2.20. Figure 2.14 on page 27 shows the toad and the newt.



▲ **Figure 2.20** *Rana* (×0.75)

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

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

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

Frogs and toads migrate to ponds where the males and females pair up. The male climbs on the female's back and grips firmly with his front legs (see Figure 2.21). When the female lays eggs, the male immediately releases sperms over them. Fertilisation, therefore, is external even though the frogs are in close contact for the event.

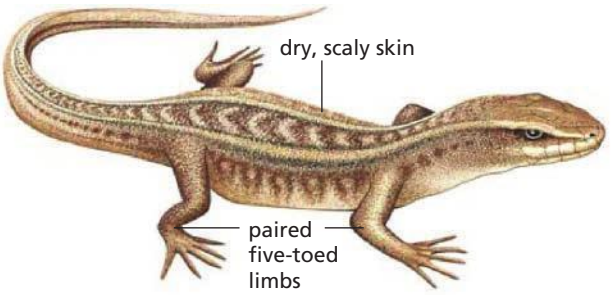
▲ **Figure 2.21** Frogs pairing. The male clings to the female's back and releases his sperm as she lays the eggs

Reptiles

Reptiles are land-living vertebrates. Their skins are dry and the outer layer of epidermis forms a pattern of scales. This dry, scaly skin helps reduce water loss. Also, the eggs of most species have a tough, rubbery shell. So, reptiles are not limited to damp habitats, and they do not need water in which to breed.

Reptiles are cold-blooded, but they can try to regulate their temperature. They do this by lying in the sun until their bodies warm up. When reptiles warm up, they can move about rapidly to chase insects and other prey.

Reptiles include lizards, snakes, turtles, tortoises and crocodiles (see Figure 2.22 and Figure 2.14 on page 27).



▲ **Figure 2.22** *Lacerta* (×1.5)

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

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

Birds

Birds are warm-blooded vertebrates.

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

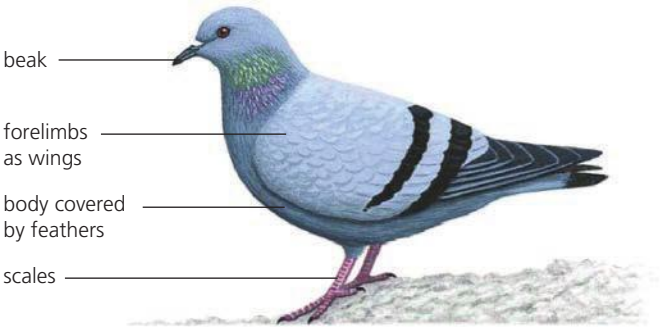
The epidermis over most of the body produces a covering of feathers but, on the legs and toes, the epidermis forms scales. The feathers are of several kinds. The fluffy down feathers form an insulating layer close to the skin; the contour feathers cover the body and give the bird its shape and coloration;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

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

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

Figure 2.23 shows the main features of a bird.

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



▲ **Figure 2.23** The main features of a pigeon (×0.14)

Mammals

Mammals are warm-blooded vertebrates with four limbs. They differ from birds because they have hair rather than feathers. Unlike the other vertebrates, they have a diaphragm, which plays a part in breathing (see Chapter 9). They also have mammary glands and suckle their young on milk.

A sample of mammals is shown in Figure 2.14 on page 27 and Figure 2.24 shows some of the mammalian features.

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

▲ **Figure 2.24** Mammalian features. The furry coat, the external ear flaps (pinnae) and the facial whiskers are visible mammalian features in this gerbil

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

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

▼ **Table 2.2** Key features of the five classes of vertebrates

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

Test yourself

6 Make up a mnemonic involving the five classes of vertebrates.
Test yourself using your mnemonic to see if it helps you remember the classes.

7 Which of the vertebrate classes have
- **a** cold blood
- **b** scaly skin
- **c** external fertilisation
- **d** gills for breathing?

8 Why do you think cold-blooded animals are slowed down by low temperatures? (See Chapter 5.)

The five-kingdom scheme

The kingdom is the largest group of organisms recognised by biologists. But how many kingdoms should there be? Most biologists used to opt for the use of two kingdoms: Plant and Animal. This, however, caused problems in trying to classify fungi, bacteria and single-celled organisms, which do not fit obviously into either kingdom.

Many biologists now favour the five-kingdom scheme. This is a scheme that consists of Animal, Plant, **Fungus**, Prokaryote and **Protoctist**.

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

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

This kind of problem will always occur when we try to come up with rigid classification schemes with clear boundaries between groups. The process of evolution cannot be expected to result in a tidy scheme of classification for biologists to use.

Going further

The three-domain scheme

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

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

A summary of the classification schemes proposed by scientists is shown in Figure 2.25.

A two-kingdom scheme: Linnaeus

Animal	Plant

A five-kingdom scheme: Whittaker

Animal	Plant	Fungus	Prokaryote	Protoctist

A six-kingdom system: Woese

Animal	Plant	Fungus	Eubacteria	Archaebacteria	Protoctist

A three-domain system: Woese

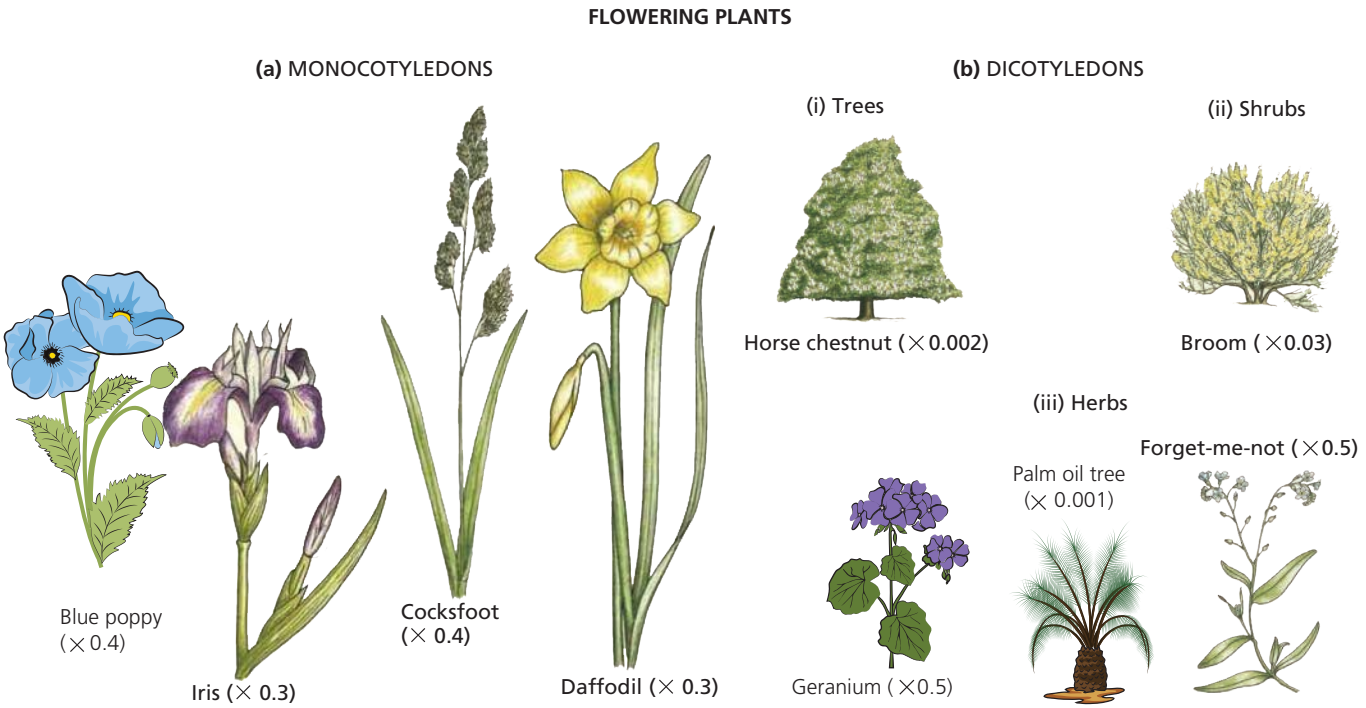
Eubacteria	Archaea	Eukarya

▲ **Figure 2.25** A summary of the classification schemes proposed by scientists

The plant kingdom

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

The syllabus only requires knowledge of two groups – ferns and flowering plants.



▲ **Figure 2.26** The plant kingdom; flowering plants

Ferns

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

The stem is usually completely below ground. In bracken, the stem grows horizontally below ground, sending up leaves at intervals. Roots grow directly from the stem.

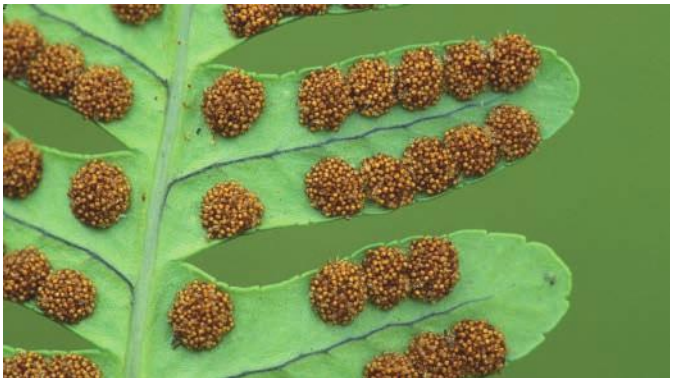
The stem and leaves have sieve tubes and water-conducting cells like those in the xylem and phloem of a flowering plant (see Chapter 7).

The leaves of ferns vary from one species to another (see Figures 2.27 and 2.28), but they are all several cells thick. Most of them have an upper and lower epidermis, a layer of palisade cells and a **spongy mesophyll**, like the leaves of a flowering plant.

▲ **Figure 2.27** Young fern leaves. Ferns do not form buds like those of the flowering plants. The midrib and leaflets of the young leaf are tightly coiled and unwind as it grows

▲ **Figure 2.28** The plant kingdom; ferns – one group of plants that does not bear seeds

Ferns produce **gametes** but no seeds. The **zygote** gives rise to the fern plant, which then produces single-celled spores from many **sporangia** (spore capsules) on its leaves. The sporangia are formed on the lower side of the leaf, but their position depends on the species of fern. The sporangia are usually arranged in compact groups (see Figure 2.29).

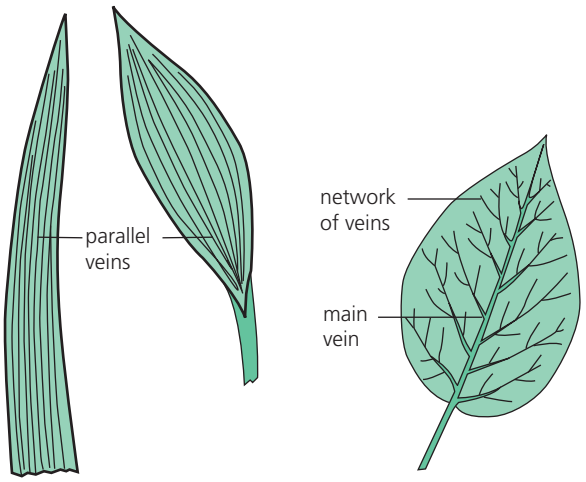


▲ **Figure 2.29** Polypody fern. Each brown patch on the underside of the leaf is made up of many sporangia

Flowering plants

Flowering plants reproduce by seeds that are formed in flowers. The seeds are enclosed in an **ovary**. The general structure of flowering plants is described in Chapter 7. Examples are shown in Figure 2.26 on page 34. Flowering plants are divided into two subclasses: **monocotyledons** and **dicotyledons**. Monocotyledons (monocots for short) are flowering plants that have only one **cotyledon** in their seeds. A cotyledon is an embryonic leaf which often contains food stores. Most, but not all, monocots also have long, narrow leaves (e.g. grasses, daffodils, bluebells) with parallel leaf veins (see Figure 2.30(a)).

The dicotyledons (dicots for short) have two cotyledons in their seeds. Their leaves are usually broad, and the leaf veins form a branching network (see Figure 2.30(b)).



(a) monocot leaves **(b)** a dicot leaf

▲ **Figure 2.30** Leaf types in flowering plants

The key features of monocots and dicots are summarised in Table 2.3.

▼ **Table 2.3** Summary of the key features of monocots and dicots

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

Test yourself

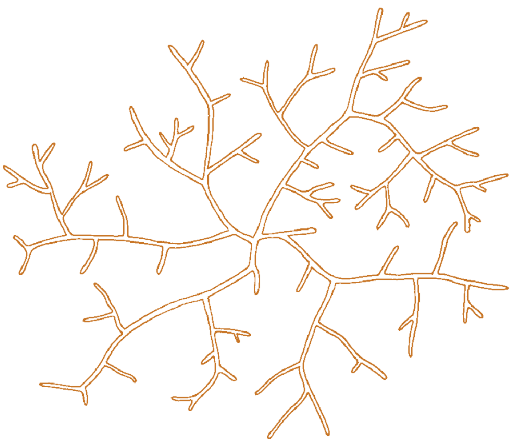
9 The white deadnettle is *Lamium album*; the red deadnettle is *Lamium purpureum*. Would you expect these two plants to cross-pollinate successfully? Explain your answer.

10 If a fire destroys all the above-ground vegetation, the bracken (a type of fern) will still grow well in the next season. Suggest why this is so.

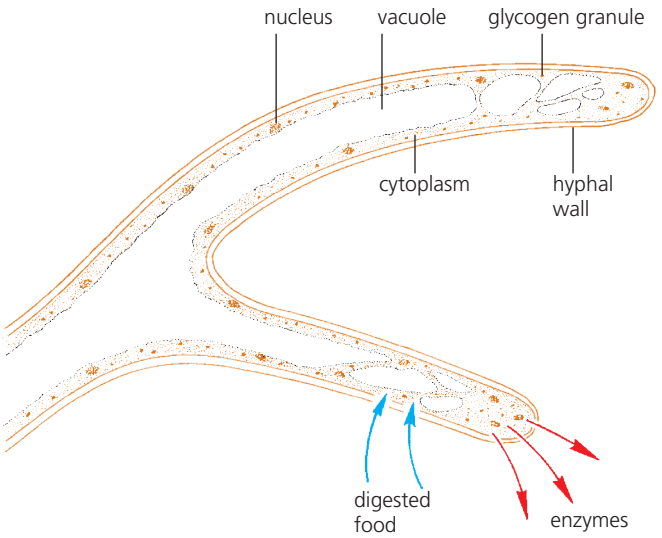
As well as knowing the features used to place animals and plants into the appropriate kingdoms, you also need to know the main features of the following kingdoms: Fungus, Prokaryote and Protoctist.

The Fungi kingdom

Most fungi are made up of thread-like *hyphae* (see Figure 2.31), rather than cells, and there are many nuclei scattered throughout the cytoplasm in their hyphae (see Figure 2.32).



▲ **Figure 2.31** The branching hyphae form a mycelium



▲ **Figure 2.32** The structure of fungal hyphae

The fungi include organisms such as mushrooms, toadstools, puffballs and the bracket fungi that grow on tree trunks (Figure 2.33). There are also the less obvious, but very important, mould fungi, which grow on stale bread, cheese, **fruit** or other food. Many of the mould fungi live in the soil or in dead wood. The yeasts are single-celled fungi that have some features similar to moulds.

Some fungal species are parasites, as is the bracket fungus shown in Figure 2.33.

A parasite is an organism living on another organism (the host), gaining food and shelter from it. It is a very one-sided relationship.

Fungal parasites live in other organisms, particularly plants, where they cause **diseases** that can affect crop plants, such as the mildew shown in Figure 2.34. (See also Chapter 12.)

▲ **Figure 2.33** A parasitic fungus. The 'brackets' are the reproductive structures. The mycelium in the trunk will eventually kill the tree

▲ **Figure 2.34** Mildew on wheat. Most of the hyphae are inside the leaves, digesting the cells, but some grow out and produce the powdery spores seen here

The Prokaryote kingdom

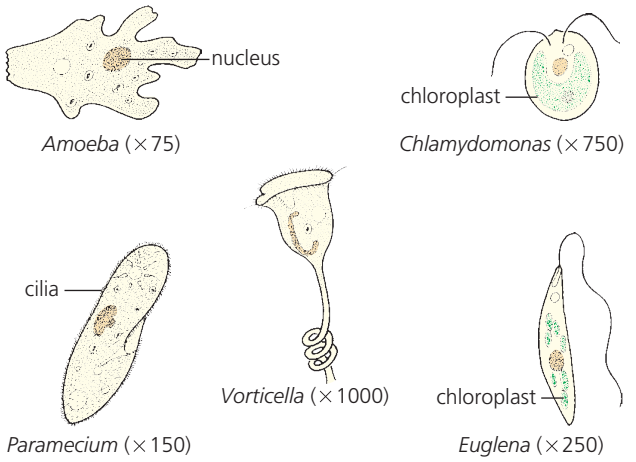
These are the bacteria and the blue-green algae. They consist of single cells but are different from other single-celled organisms because their chromosomes are not organised into a nucleus. The structure of bacterial cells is described in Chapter 1, pages 6–7.

The Protoctist kingdom

These are single-celled (unicellular) organisms which have their chromosomes enclosed in a nuclear membrane to form a nucleus. Some examples are shown in Figure 2.35.

Some of the Protoctista (e.g. *Euglena*) have chloroplasts and make their food by photosynthesis. These Protoctista are often referred to as unicellular. Organisms like *Amoeba* and *Paramecium* take in and digest solid food and so are animal-like in their feeding. They may be called unicellular 'animals'.

Amoeba is a protozoan that moves by a flowing movement of its cytoplasm. It feeds by picking up bacteria and other microscopic organisms as it moves. *Vorticella* has a stalk that can contract and feeds by making a current of water with its cilia (tiny hair-like organelles which project from the cell surface). The current brings particles of food to the cell. *Euglena* and *Chlamydomonas* have chloroplasts in their cells and feed, like plants, by photosynthesis.



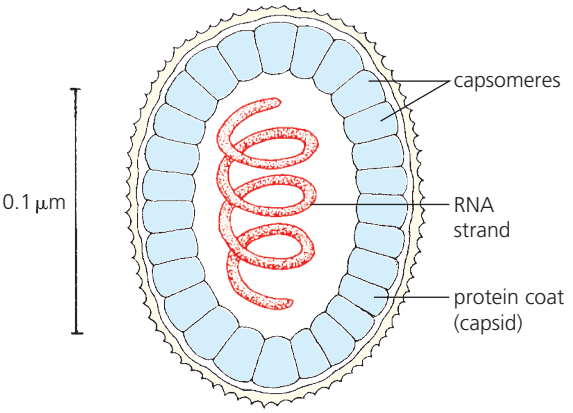
▲ **Figure 2.35** Protoctista. *Chlamydomonas* and *Euglena* have chloroplasts and can photosynthesise. The others are protozoa and ingest (take in) solid food

Viruses

There are many different types of virus and they vary in their shape and structure. All viruses, however, have a central core of RNA or DNA (see Chapter 17) surrounded by a protein coat. Viruses have no nucleus, cytoplasm, cell organelles or cell membrane, though some forms have a membrane outside their protein coats.

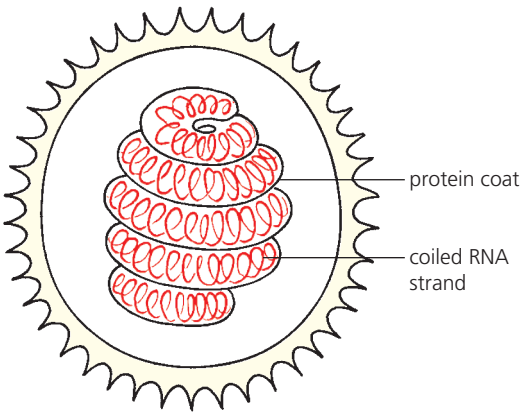
So, virus particles are not cells. They do not feed, respire, excrete or grow, and it is arguable whether they can be classed as living organisms. Viruses do reproduce, but only inside the cells of living organisms, using materials provided by the host cell.

A generalised virus particle is shown in Figure 2.36. The nucleic acid core is a coiled single strand of RNA with a protein coat. The protein coat is called a capsid.



▲ **Figure 2.36** Generalised structure of a virus

One example of a virus is the influenza virus (Figure 2.37).



▲ **Figure 2.37** Structure of the influenza virus

Test yourself

11 Figure 2.35 shows some Protoctista. Using only the features shown in the drawings, construct a dichotomous key that could be used to identify these organisms.

12 Classify the following organisms: beetle, sparrow, weasel, gorilla, bracken, buttercup. For example, butterfly: Kingdom, animal; Group, arthropod; Class, insect.

13 Which kingdoms contain organisms with
- **a** many cells
- **b** nuclei in their cells
- **c** cell walls
- **d** hyphae
- **e** chloroplasts?

Revision checklist

After studying Chapter 2 you should know and understand the following:

- ✔ A species is a group of organisms that can reproduce to produce fertile offspring.
- ✔ The binomial system of naming species is an internationally agreed system in which the scientific name of an organism is made up of two parts, showing the genus and species.
- ✔ Keys are used to identify unfamiliar organisms, with dichotomous keys having two branches at each stage.
- ✔ The sequences of bases in DNA are used as a means of classification.
- ✔ Groups of organisms that share a more recent ancestor (are more closely related) have more similar base sequences in their DNA than those that share only a distant ancestor.
- ✔ Animals get their food by eating plants or other animals.
- ✔ Plants make their food by photosynthesis.
- ✔ Arthropods have a hard exoskeleton and jointed legs. The classes of arthropods are arachnids, insects, crustaceans and myriapods.
- ✔ Vertebrates have a spinal column and skull.
- ✔ The classes of vertebrates are amphibia, birds, fish, mammals and reptiles.
- ✔ Prokaryotes are microscopic organisms; they have no proper nucleus.
- ✔ Protoctists are single-celled organisms containing a nucleus.
- ✔ Fungi are made up of thread-like hyphae. They reproduce by spores.
- ✔ Ferns have well developed stems, leaves and roots. They reproduce by spores.
- ✔ Seed-bearing plants reproduce by seeds.
- ✔ Flowering plants have flowers; their seeds are in an ovary which forms a fruit. They are subdivided into monocots and dicots.
- ✔ Viruses do not possess the features of a living organism.
- ✔ Viruses can only reproduce in living cells.

Exam-style questions

1 a Define the term *species*. [2]

b With reference to the tiger, *Panthera tigris*, what does the term *binomial system* mean? [3]

2 a State the main characteristics of arthropods. [3]

b By means of a table, state three differences between insects and myriapods. [3]

3 List the main characteristics of

a a fungus [3]

b a bacterium. [3]

4 Design a dichotomous key to divide the vertebrates into classes. Give one example of a species of each of the classes named in your key. Start with the question, 'Is the animal warm-blooded?' [7]

5 The table shows the proportions of all known species in each of the main groups of organisms.

Group of organisms	Proportion of all known species/%
arachnids	4.5
bacteria, viruses	0.5
crustaceans	2.4
fungi	4.2
insects	56.3
other arthropods	1.2
other invertebrates (not arthropods)	9.1
plants	14.3
protoctists	4.8
vertebrates	2.7

a i) Apart from insects, which group of organisms has the most known species? [1]

ii) Assuming that there are four groups of arthropods, what percentage of all known species are myriapods? [1]

iii) Fungi are listed separately from plants. State two reasons why fungi **are not** classified as plants. [2]

b Using data from the table, calculate what percentage of arthropods are arachnids. [2]

c i) Birds and fish are two classes of vertebrates. State the names of the other three classes. [3]

ii) State one feature that distinguishes fish from all the other vertebrate classes. [1]

d It is estimated that 1.9 million species of organisms have been named. Use data from the table to calculate the total number of insects known. Show your working. [2]

6 a Distinguish between the following groups of organisms:

i) monocotyledons and dicotyledons [4]

ii) amphibians and reptiles [4]

b Define the term *binomial system*. State one example to support your answer. [3]

3 Movement into and out of cells

Focus

In the previous chapter, you were introduced to reasons for classifying organisms into groups and the use of the binomial system of naming species. You had the opportunity to develop your own dichotomous keys based on identifiable features. Then you learned about some of the main animal and plant groups and their features. In this chapter, you will find out about how materials move into and out of cells. These materials include gases like oxygen and carbon dioxide, water, mineral ions, waste products and nutrients. How does the cell protect itself from gaining substances that could be toxic, or from losing vital resources? How can a plant keep its shape if it has no clear means of support? By studying the chapter carefully and following the practical suggestions, you should be able to answer these questions.

Cells need food materials, which they can respire for energy or use to build up their cell structures. They also need mineral ions and water, which play a part in chemical reactions in the cell. Finally, they need to get rid of substances like carbon dioxide, which would upset some of the chemical reactions or even poison the cell if they built up.

Substances may pass through the cell membrane either passively by **diffusion** or actively by some form of **active transport**.

Diffusion

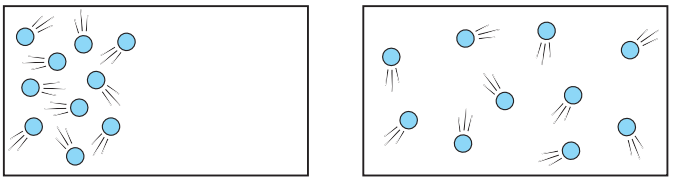
FOCUS POINTS

- ★ What is diffusion?
- ★ Where does the energy for diffusion come from?
- ★ How do substances move into and out of the cell by diffusion?
- ★ How important is diffusion to living organisms?
- ★ What effects do surface area, temperature, concentration gradient and distance have on diffusion?

Key definitions

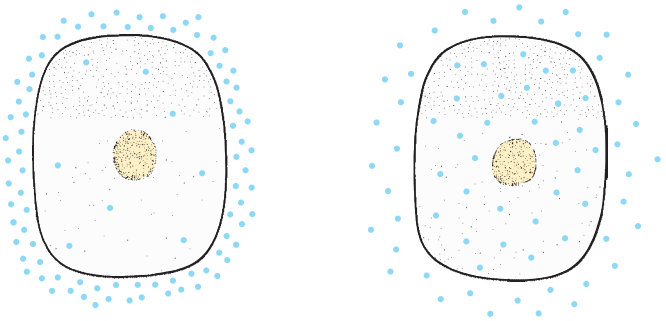
Diffusion is the net movement of particles from a region of their higher concentration to a region of their lower concentration (i.e. down a **concentration gradient**), as a result of their random movement.

The molecules of a gas like oxygen are moving about all the time. So are the molecules of a liquid or a substance like sugar dissolved in water. As a result of this movement, the molecules spread themselves out evenly to fill all the available space (Figure 3.1).



▲ **Figure 3.1** Diffusion

This process is called diffusion. One effect of diffusion is that the molecules of a gas, a liquid or a dissolved substance will move from a region where there are a lot of them (i.e. concentrated) to regions where there are few of them (i.e. less concentrated), until the concentration everywhere is the same. In most organisms substances have to move through cell membranes. Some substances move by diffusion. Figure 3.2(a) is a diagram of a cell with a high concentration of molecules (e.g. oxygen) outside and a low concentration inside. The effect of this difference in concentration is to make the molecules diffuse into the cell until the concentration inside and outside is the same, as shown in Figure 3.2(b).



(a) greater concentration outside cell

(b) concentrations equal on both sides of the cell membrane

▲ **Figure 3.2** Molecules entering a cell by diffusion

Whether this will happen or not depends on if the cell membrane will let the molecules through. Small molecules like water (H_2O), carbon dioxide (CO_2) and oxygen (O_2) can pass through the cell membrane quite easily. So, diffusion tends to balance the concentration of these molecules inside and outside the cell all the time.

When a cell uses oxygen for its aerobic respiration, the concentration of oxygen inside the cell falls and so oxygen molecules diffuse into the cell until the concentration is raised again. During tissue respiration, carbon dioxide is released and so its concentration inside the cell increases. Once again diffusion takes place, but this time the molecules move out of the cell. In this way, diffusion can explain how a cell takes in its oxygen and gets rid of its carbon dioxide.

The importance of diffusion of gases and solutes

Gases

Most living things need a reliable source of oxygen for respiration. This moves into the organism by diffusion down a concentration gradient. Small animals with a large surface area to volume **ratio** may get oxygen through their body surface. Larger animals need **gas exchange** organs like lungs or gills, which provide a large surface area for gas exchange. They also need a circulatory system to move the oxygen to all their cells. Carbon dioxide, released during aerobic respiration is removed in the same way, by diffusion.

Photosynthetic plants need carbon dioxide for making their food. This diffuses through the **stomata** in the leaves (see Chapter 7) into the air spaces in the mesophyll, before reaching the palisade cells. Oxygen produced during photosynthesis, as well as water vapour from the transpiration stream, diffuses out of the leaf through the stomata. The rate of diffusion of water vapour depends on the temperature, humidity and wind speed (see 'Water uptake' in Chapter 7). Any oxygen needed for respiration (some is produced by photosynthesis) and carbon dioxide produced (some is used up by photosynthesis) also diffuses through the stomata of the leaves.

Going further

Nitrogen is the most common gas in the **atmosphere** (78% of the air is nitrogen). Nitrogen gas also enters the bloodstream by diffusion, but it is not used by the body. It is an inert (unreactive) gas so normally it causes no problems. However, divers are at risk. As a diver swims deeper, the surrounding water pressure increases. This raises the pressure in the diver's air tank. An increase in nitrogen pressure in the air tank results in more nitrogen diffusing into the diver's tissues, the amount increasing the longer the diver stays at depth. Nitrogen is not used by the body tissues, so it builds up.

When the diver begins to return to the surface of the water, the pressure decreases and the nitrogen can come out of solution, forming bubbles in the blood if the diver goes back to the surface too quickly. These bubbles can block blood flow and become stuck in joints, resulting in a condition called decompression sickness, or 'the bends'. Unless the diver goes up slowly in planned stages, the effect of the nitrogen bubbles can be lethal and can only be stopped by rapid recompression.

Solutes

Scientists think that some mineral ions in solution, like **nitrates** and magnesium, diffuse across the tissues of plant roots, but that most are absorbed into the roots by active transport.

In the **ileum**, water-soluble vitamins like vitamin C are absorbed into the bloodstream by diffusion.

In the kidneys, some solutes, like **urea** and mineral ions, pass back into the bloodstream by diffusion. At first, **glucose** is reabsorbed by diffusion, but active transport is also involved.

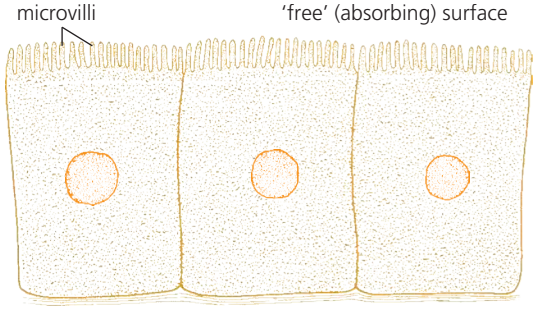
Rates of diffusion

Molecules and ions in liquids and gases move around randomly using **kinetic energy** (energy from movement). The speed with which a substance diffuses through a cell wall or cell membrane will depend on many conditions, including:

- the surface area across which the diffusion is happening
- the temperature
- the difference between its concentration inside and outside the cell
- the distance it diffuses.

Surface area

If 100 molecules diffuse through 1 mm^2 of a membrane in one minute, then an area of 2 mm^2 should allow twice as many molecules through in the same time. So, the rate of diffusion into a cell will depend on the cell's surface area. A larger surface area will result in faster diffusion. Cells which are involved in rapid **absorption**, like those in the kidney or the intestine, often have their exposed surface membrane formed into hundreds of tiny projections called **microvilli** (see Figure 3.3). These increase the absorbing surface to make diffusion faster.



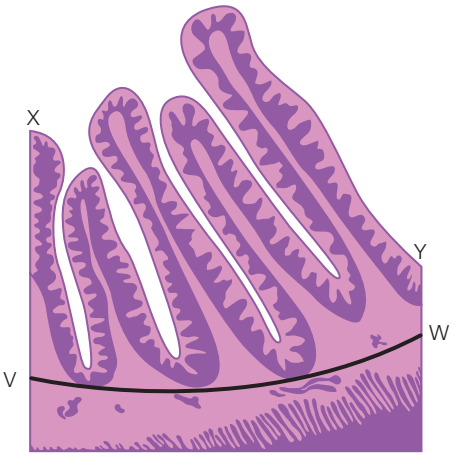
▲ **Figure 3.3** Microvilli

The shape of a cell will also affect the surface area. For example, the cell in Figure 3.4(a) has a greater surface area than the cell in Figure 3.4(b), even though they both have the same volume.

▲ **Figure 3.4** Surface area

Worked example

The diagram in Figure 3.5 shows a section of the small intestine, with **villi**. These increase the surface area to make the diffusion of digested food molecules more efficient.



▲ **Figure 3.5** Section through the small intestine to show villi

Tasks

1 Use a piece of cotton or string.
Hold one end of the cotton against point X. Now spread the cotton along the surface of the villi, weaving downwards and upwards until you reach point Y. Use a pen to mark this point on the cotton.
Now hold the cotton against a ruler and measure its length. Record this length as the length between X and Y. It may take two or more attempts to follow the surface of the villi from X to Y. It works best to trap the end of the cotton at point X, then lie the cotton a short distance, for example, until the first bend and trap it with a finger from your other hand. Then lie the cotton along the next section and keep repeating the procedure until you get to point Y.

2 Repeat the process, measuring V to W, which is the length the surface would be without the presence of villi. Record this length.

3 Calculate the percentage increase in length by comparing X to Y (the surface with villi) with V to W (the surface without villi).
To calculate the percentage increase in length

$$\%\,\text{increase} = \frac{\text{change in length (X to Y)} - \text{(V to W)}}{\text{original length (V to W)}} \times 100$$

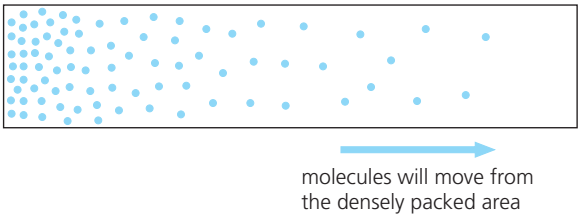
The percentage increase shows how important the villi are in the small intestine for increasing the surface area for absorption of digested food molecules.
Bear in mind that this increase does not take into account the presence of microvilli!

Temperature

An increase in temperature gives molecules and ions more kinetic energy. This allows them to move faster, so the process of diffusion speeds up.

Concentration gradient

The greater the difference in the concentration of a substance on either side of a membrane, the faster it will diffuse. The difference is called a concentration gradient (Figure 3.6). If a substance on one side of a membrane is steadily removed, the concentration gradient stays the same. When oxygen molecules enter a red blood cell they combine with a chemical (**haemoglobin**), which takes them out of solution. So, the concentration of free oxygen molecules inside the cell is kept very low and the concentration gradient for oxygen stays the same.



▲ **Figure 3.6** Concentration gradient

Distance

Cell membranes are all about the same thickness (approximately 0.007 µm), but plant cell walls vary in their thickness and **permeability** (how easily materials pass through them). Usually, the thicker the wall, the slower the rate of diffusion. When oxygen diffuses from the **alveoli** of the lungs into red blood cells, it travels through the cell membranes of the alveoli, the blood capillaries and the red blood cells, as well as the cytoplasm of each cell. This increased distance slows down the diffusion rate.

Practical work

Safety

- Eye protection must be worn.
- Note your teacher's advice for using a knife.
- Take care using methylene blue or potassium permanganate solution – they will stain skin and clothing.
- Take care with hot water handling.

Experiments on diffusion

1 Diffusion and surface area

- Use a block of starch agar or gelatine at least 3 cm thick. Using a ruler and a sharp knife, measure and cut four cubes from the jelly with sides of 3.0 cm, 2.0 cm, 1.0 cm and 0.5 cm.
- Place the cubes into a beaker of methylene blue dye or potassium permanganate solution.
- After 15 minutes, remove the cubes with forceps and place them on to a white tile.
- Cut each of the cubes in half and measure the depth to which the dye has diffused.

2 Diffusion and temperature

- Set up two beakers with equal volumes of hot water and iced water.
- Add a few grains of potassium permanganate to each beaker and observe how quickly the dissolved dye spreads through the water in each beaker. An alternative is to use tea bags.

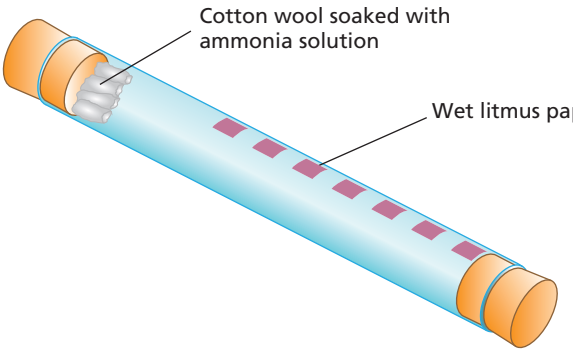
Safety

- Eye protection must be worn.
- Take care, concentrated ammonia solution is corrosive and irritant and should only be used in a fume cupboard. Wear disposable gloves.

3 Diffusion and concentration gradients and distance (teacher demonstration only)

- This demonstration should be carried out in a fume cupboard.
- Wear disposable gloves as concentrated ammonia is corrosive and pungent.
- Use a wide glass tube that is at least 30 cm long and corked at one end. Using a glass rod or wire, push squares of moist red litmus paper into the tube, so that they stick to the side, as shown in Figure 3.7. (It is a good idea to mark 2 cm intervals along the outside of the tube, starting at 10 cm from one end, with a permanent marker or white correction fluid before inserting the litmus paper.)

- Close the open end of the tube with a cork carrying a plug of cotton wool saturated with a strong solution of ammonia. Start a stopwatch.
- Observe and record the time when each square of litmus starts to turn blue. Use this information to calculate the rate at which the alkaline ammonia vapour diffuses along the tube.
- Repeat the experiment using a dilute solution of ammonia.
- Plot both sets of results on a graph, labelling each plot line.



▲ **Figure 3.7** Experiment to measure the rate of diffusion of ammonia in air

Practical work questions

1 Calculate the surface area and volume of each cube used in experiment 1 and construct a table of your data. Remember to state the units in the heading for each column.

2 Imagine that the cubes in experiment 1 are animals, with the jelly representing living cells and the dye representing oxygen. Which of the 'animals' would be able to get enough oxygen by diffusion through their surface to keep them alive? Explain your answer.

3 Try cutting different shapes, for example, cutting a block 3.0 cm long, 1.0 cm wide and 0.5 cm deep. Research what type of animal this would represent and how this type of animal obtains its oxygen.

4 Explain the results you observed in experiment 2.

5 A 10% solution of copper sulfate is separated by a partially permeable membrane from a 5% solution of copper sulfate.
Will water diffuse from the 10% solution to the 5% solution or from the 5% solution to the 10% solution? Explain your answer.

6 If a fresh beetroot is cut up, the pieces washed in water and then left for an hour in a beaker of water, little or no red pigment escapes from the cells into the water. If the beetroot is boiled first, the pigment does escape into the water. Using your knowledge of the properties of a living cell membrane, explain the difference in results.

7 In experiment 3, which ammonia solution diffused faster? Can you explain why?

8 Study the graph you produced for experiment 3. What happened to the rate of diffusion as the ammonia travelled further along the tube? Can you explain why?

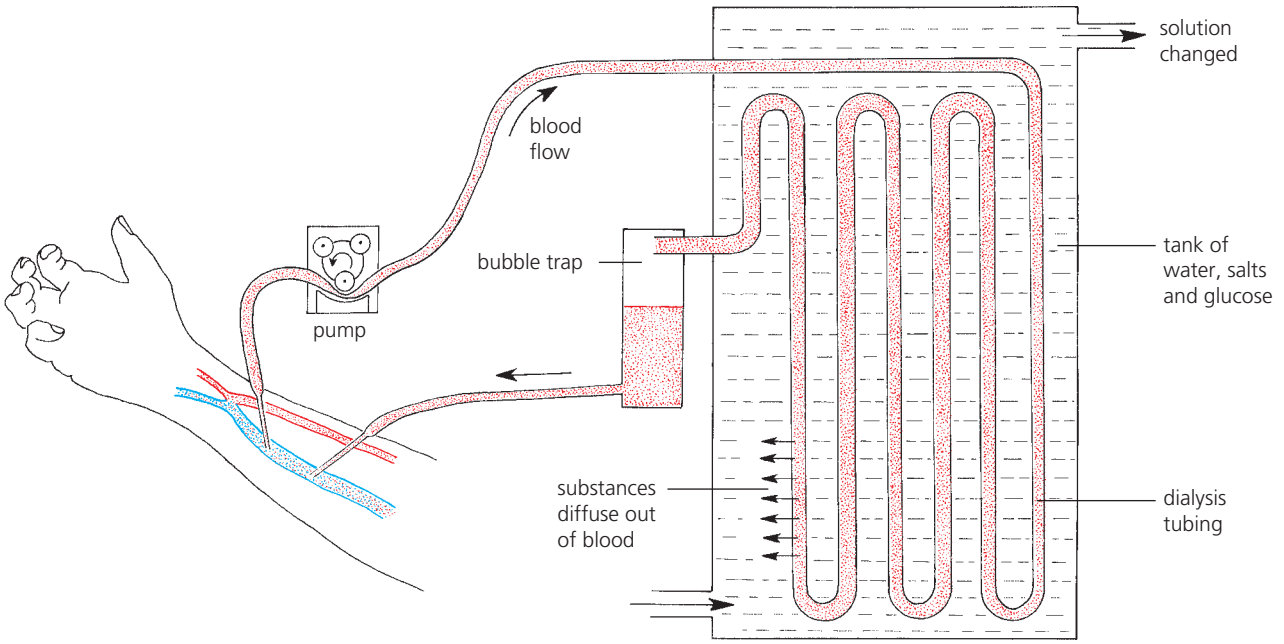
Going further

Artificial partially permeable membranes are made from cellulose acetate in sheets or tubes. These are used for a process called dialysis for patients suffering from kidney failure. The pore size can be altered during manufacture so that large molecules cannot get through at all.

The dialysis machine ('artificial kidney')

Kidney failure can be the result of an accident involving a drop in blood pressure or of a disease of the kidneys. In the first example, recovery is usually natural and quick, but if it takes longer than 2 weeks, the patient can die because of a potassium imbalance in the blood. This causes heart failure. In the case of kidney disease, the patient can stay alive with only one kidney, but if both fail, the patient's blood composition has to be controlled by a dialysis machine. In the same way, the accident victim can be kept alive on a dialysis machine until their blood pressure is returned to normal.

Simply, a dialysis machine consists of a long cellulose tube coiled up in a water-bath. The patient's blood is led from a vein in the arm and pumped through the cellulose (dialysis) tubing (Figures 3.8 and 3.9). The tiny pores in the **dialysis tubing** allow small molecules, like those of salts, glucose and urea, to leak out into the water-bath. Blood cells and protein molecules are too large to get through the pores (see experiment 5 on page 52). This stage is like the filtration process in the **glomerulus** (see Chapter 13).



▲ **Figure 3.8** The principle of the kidney dialysis machine

To prevent a loss of glucose and important mineral ions from the blood, the water-bath contains a solution of mineral ions and sugar of the correct composition, so that only the substances above this concentration can diffuse out of the blood into the bathing solution. In this way, urea and excess mineral ions are removed.

The bathing solution is also kept at body temperature and is regularly changed as the unwanted blood solutes build up in it. The blood is then returned to the patient's arm vein.

A patient with total kidney failure spends 2 or 3 nights each week connected to the machine (Figure 3.9). With this treatment and a carefully controlled diet, the patient can lead quite a normal life. A kidney transplant is a better solution though, because then the patient does not need to use a dialysis machine.

▲ **Figure 3.9** Kidney dialysis machine. The patient's blood is pumped to the dialyser, which removes urea and excess mineral ions

Test yourself

1 Look at Figure 11.19 on page 178. The symbol O_2 is an oxygen molecule.
Explain why oxygen is entering the cells drawn on the left but leaving the cells on the right.

2 Look at Figure 9.5 on page 142. It shows one of the small air pockets (an alveolus) that form the lung.
   a Suggest a reason why the oxygen and carbon dioxide are diffusing in opposite directions.
   b What might happen to the rate of diffusion if the blood flow were to speed up?

Osmosis

FOCUS POINTS

- ★ What is osmosis?
- ★ What is the role of water in living organisms?
- ★ How does water move into and out of cells by osmosis?
- ★ What role does water have in supporting plants?
- ★ How would you investigate osmosis?
- ★ What is the effect of immersing plant cells in solutions of different concentrations?
- ★ What do the terms turgid, turgor pressure, plasmolysis, flaccid and water potential mean?

Key definitions

Osmosis is the net movement of water molecules from a region of higher **water potential** to a region of lower water potential through a partially permeable membrane.

Roles of water

Most cells contain about 75% water and will die if their water content falls much below this. Water is a good solvent and many substances move about the cells in a watery solution.

Water molecules take part in many vital chemical reactions. For example, in green plants, water combines with carbon dioxide to form glucose (see Chapter 6). In animals, water helps to break down and dissolve food molecules (see 'Chemical digestion' in Chapter 8). Blood is made up of cells and a liquid called **plasma**. This plasma is 92% water and is a way of transporting many dissolved substances, like carbon dioxide, urea, digested food and **hormones**. Blood cells are carried around the body in the plasma.

Water is also a way of transporting materials in plants. Water passes up the plant from the roots to the leaves in xylem vessels and carries dissolved mineral ions. Phloem vessels transport dissolved sugars and amino acids from the leaves to where they are used or stored (see Chapter 7).

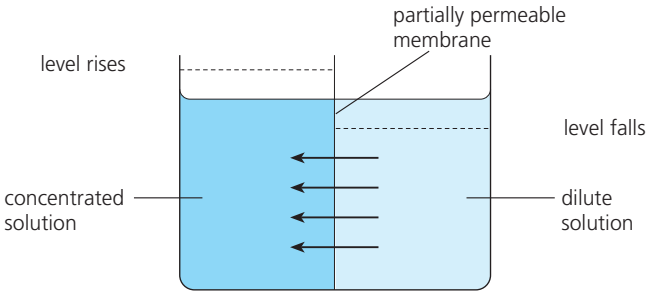
Water is important in the process of **excretion** in animals. It is a powerful solvent for excretory materials, like nitrogenous molecules (e.g. urea), as well as mineral ions, used hormones and **drugs**. The water has a diluting effect, so excretory materials are less toxic (poisonous).

Going further

The physical and chemical properties of water are different from those of most other liquids. These make it uniquely effective in helping living activities. For example, water has a high capacity for heat (high thermal capacity). This means that it can absorb a lot of heat without its temperature rising to levels that damage the proteins in the cytoplasm. However, because water freezes at 0 °C most cells are damaged if their temperature falls below this and ice crystals form in the cytoplasm. (Despite this, rapid freezing of cells in liquid nitrogen at below –196 °C does not harm them.)

Diffusion of water

If a dilute solution is separated from a concentrated solution by a partially permeable membrane, water diffuses across the membrane from the dilute to the concentrated solution. This is called osmosis and is shown in Figure 3.10.



▲ **Figure 3.10** Osmosis. Water will diffuse from the dilute solution to the concentrated solution through the partially permeable membrane. As a result, the liquid level will rise on the left and fall on the right

A partially permeable membrane is permeable but allows water to pass through more rapidly than dissolved substances.

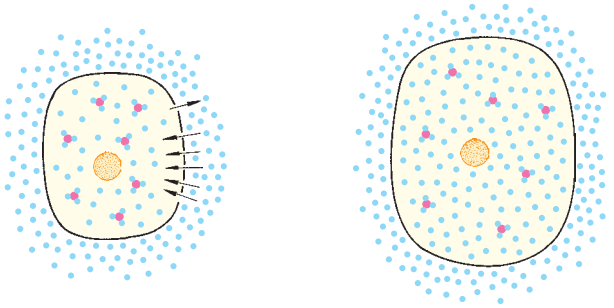
Since a dilute solution effectively contains more water molecules than a concentrated solution, there

is a concentration gradient, which encourages the passage of water from the dilute solution to the concentrated solution.

In living cells, the cell membrane is partially permeable and the cytoplasm and vacuole (in plant cells) contain dissolved substances. As a result, water tends to diffuse into cells by osmosis if they are surrounded by a weak solution (e.g. fresh water). If the cells are surrounded by a stronger solution (e.g. sea water), the cells may lose water by osmosis. These effects are described more fully later.

Animal cells

The cell in Figure 3.11 is shown surrounded by pure water. Nothing is dissolved in the water; it has 100% concentration of water molecules. So, the concentration of free water molecules outside the cell is greater than the concentration of water molecules inside. As a result, water will diffuse into the cell by osmosis. The membrane allows water to go in or out. So, in our example, water can move into or out of the cell. The cell membrane is partially permeable to most of the substances dissolved in the cytoplasm. So, although the concentration of these substances inside may be high, they cannot diffuse freely out of the cell. The water molecules move into and out of the cell, but because there are more of them on the outside, they will move in faster than they move out. The liquid outside the cell does not have to be 100% pure water. If the concentration of water outside is higher than that inside, water will diffuse in by osmosis.



(a) There is a higher concentration of free water molecules outside the cell than inside, so water diffuses into the cell.

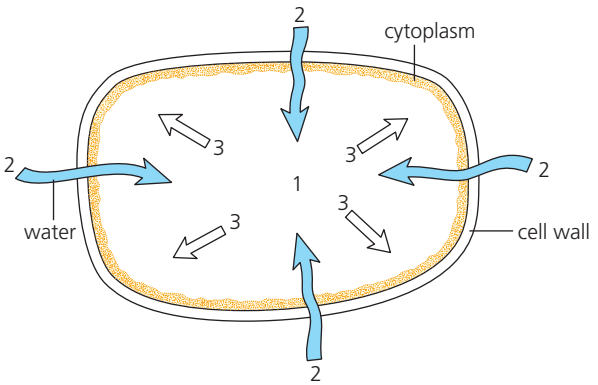
(b) The extra water makes the cell swell up.

▲ **Figure 3.11** Osmosis in an animal cell

Water entering the cell will make it swell up and, unless the extra water is removed in some way, the cell will burst. In the opposite situation, if the cells are surrounded by a solution which is more concentrated than the cytoplasm, water will pass out of the cell by osmosis and the cell will shrink. Too much uptake or loss of water by osmosis may damage cells. For this reason, it is very important that the cells in an animal's body are surrounded by a liquid which has the same concentration as the liquid inside the cells. In vertebrates, the brain monitors the concentration of the blood and the kidneys adjust it, as described in Chapter 13. By keeping the blood concentration within narrow limits, the concentration of the tissue fluid remains more or less constant (see 'Homeostasis' in Chapter 14). So, cells are not swollen by taking in too much water or dehydrated by losing too much.

Plant cells

The cytoplasm of a plant cell and the cell sap in its vacuole contain mineral ions, sugars and proteins. This reduces the concentration of free water molecules inside the cell. The cell wall is freely permeable to water and dissolved substances, but the cell membrane of the cytoplasm is partially permeable. If a plant cell is surrounded by water or a solution more dilute than its contents, water will pass into the vacuole by osmosis. The vacuole will expand and press outwards on the cytoplasm and cell wall. The cell wall of a mature plant cell does not stretch, so the inflow of water is limited by the inelastic cell wall, as shown in Figure 3.12.



1 there is a lower concentration of water in the cell sap
2 water diffuses into the vacuole
3 and makes it push out against the cell wall

▲ **Figure 3.12** Osmosis in a plant cell

This has a similar effect to blowing up a soft bicycle tyre. The tyre is like the firm cell wall, the floppy inner tube is like the cytoplasm and the air inside

is like the vacuole. If enough air is pumped in, it pushes the inner tube against the tyre and makes the tyre hard.

When plant cells have absorbed a maximum amount of water by osmosis they become very rigid, due to the pressure of water pressing outwards on the cell wall. As a result, the stems and leaves are supported. If the cells lose water, there is no longer any water pressure pressing outwards against the cell walls. So, the stems and leaves are not supported any more. At this point, the plant becomes limp and **wilts** (droops) (see Figure 3.13).

(a) plant wilting **(b)** plant recovered after watering

▲ **Figure 3.13** Wilting

Water potential

The water potential of a solution is a measure of whether it is likely to lose or gain water molecules from another solution. A dilute solution has a high proportion of free water molecules. So, it has a higher water potential than a concentrated solution. Water will flow from the dilute to the concentrated solution (from a high potential to a low potential). Pure water has the highest possible water potential because water molecules will flow from it to any other aqueous solution, even if it is very dilute. When cells containing sap with different water potentials are in contact with each other, a water potential gradient is made. Water will move from a cell with a higher water potential (a more dilute solution) to a cell with a lower water potential (a more concentrated solution). This explains one way in which water moves from root hair cells through to the xylem of a plant root (see Figure 7.3 on page 102).

The importance of water potential and osmosis in plants

A plant cell with the vacuole pushing out on the cell wall is **turgid** (it is swollen because the cell has taken up water) and the vacuole is exerting **turgor pressure** on the inelastic cell wall. Turgor pressure is the force inside the cell which pushes outwards, pushing the cell membrane against the cell wall.

If all the cells in a leaf and stem are turgid, the stem will be firm and upright. The leaves are held out straight. If the vacuoles lose water for any reason, the cells will lose their turgor (a process called **plasmolysis**) and become **flaccid**. (See experiment 9 'Plasmolysis' on pages 55–56.)

Root hair cells are touching water trapped between soil particles. When the water potential of the cell sap is lower than the water potential of the soil water, the water will enter the cells by osmosis. This gives the plant the water it needs. (This process is described in more detail in 'Water uptake' in Chapter 7.)

When a farmer spreads chemical fertiliser on the soil, the fertiliser dissolves in the soil water. Too much fertiliser can lower the water potential of the soil water. This can draw water out of the plant root hair cells by osmosis. The plants can wilt and die.

Irrigation of crops (the supply of controlled amounts of water to plants as they need it) can have a similar effect. Irrigation which provides just enough water for the plant can lead to a build-up of salts in the soil. The salts will eventually cause the soil water to have a lower water potential than the plant root cells. Crops can then no longer be grown on the land, because they wilt and die through water loss by osmosis. Much agricultural land in hot countries has become unusable because of the side-effects of irrigation (Figure 3.14).

▲ **Figure 3.14** An irrigation furrow

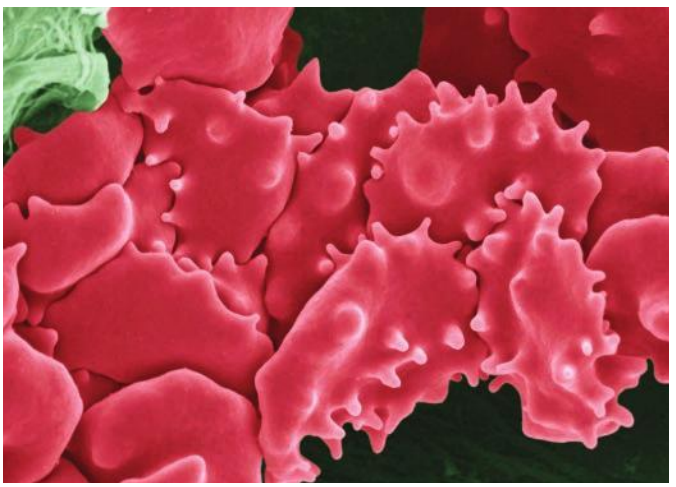
Some countries apply salt to roads in the winter to stop the formation of ice (Figure 3.15). However, vehicle wheels splash the salt on to plants at the side of the road. The build-up of salts in the roadside soil can kill plants living there, due to water loss from the roots by osmosis.

▲ **Figure 3.15** Salt gritter at work to prevent ice formation on a road

The importance of water potential and osmosis in animal cells and tissues

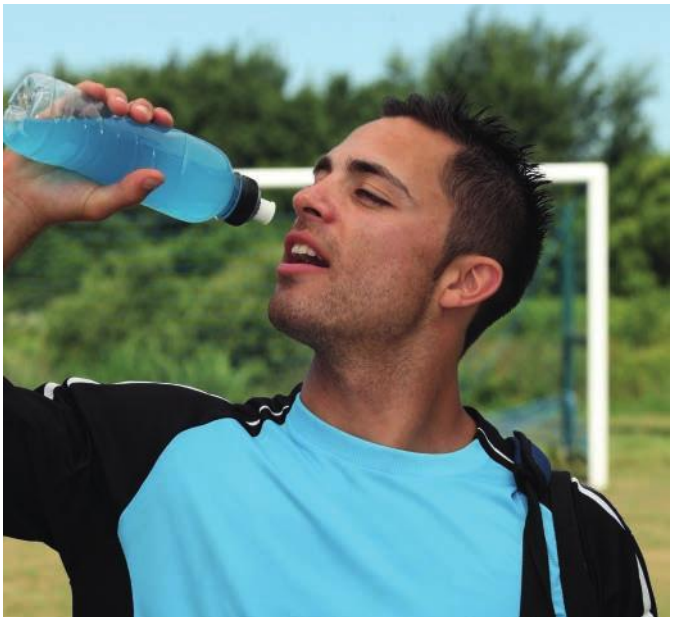
It is important that the fluid which bathes cells in animals, like tissue fluid or blood plasma, has the same water potential as the cell contents. This prevents any net flow of water into or out of the cells. If the bathing fluid has a higher water potential (a weaker concentration) than the cells, water will move into the cells by osmosis, causing them to swell up. As animal cells have no cell wall and the membrane has little strength, water would continue to enter. The cells will eventually burst. Single-celled animals like *Amoeba* (see Figure 2.35 on page 38) living in fresh water obviously have a problem. They avoid bursting by having a contractile vacuole. This collects the water as it enters the cell and regularly releases it through the cell membrane, keeping the water content of the cell under control. When surgeons carry out operations on a patient's internal organs, they sometimes need to rinse a wound. Pure water cannot be used as this would enter any cells it met and cause them to burst. A saline solution (salt solution), with the same water potential as tissue fluid, has to be used.

During physical activity, the body may sweat to keep a steady temperature. If liquids are not drunk to make up for water loss through **sweating**, the body can become dehydrated. Loss of water from the blood results in the plasma becoming more concentrated (its water potential decreases). Water is then drawn out of the red blood cells by osmosis. The cells become plasmolysed. Their surface area is reduced, so they are less effective in carrying oxygen (see Figure 3.16).



▲ **Figure 3.16** Plasmolysed red blood cells

People doing sport sometimes use sports drinks (Figure 3.17) which are isotonic (they have the same water potential as body fluids). The drinks contain water, salts and glucose. They are designed to replace lost water and salts, and provide energy, without creating osmotic problems to body cells. However, use of these drinks when not exercising vigorously can lead to weight gain in the same way as the prolonged use of any sugar-rich drink.



▲ **Figure 3.17** People may use isotonic sports drinks

Test yourself

3 Explain why the long-term use of irrigation in farming can result in making the soil unsuitable for growing crops.

4 Explain why it is more damaging for animal cells to be immersed in water than plant cells.

5 When soil becomes saturated with water, it fills up the air spaces between the soil particles. Suggest why root hair cells may die in water-logged soil.

Practical work

Safety

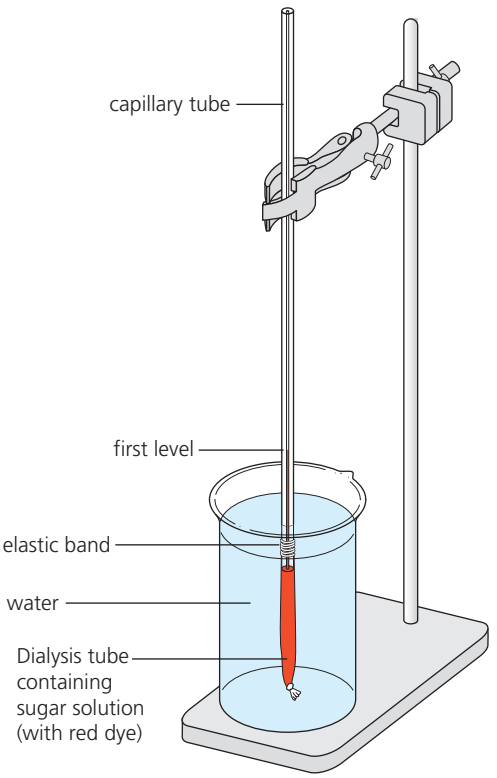
- Eye protection must be worn.
- Take care handling glass capillary tube, follow your teacher's guidance to avoid breakage.

Experiments on osmosis

Some of the experiments use 'Visking' dialysis tubing. It is made from cellulose and is partially permeable, allowing water molecules to diffuse through freely, but limiting the passage of some dissolved substances.

4 Osmosis and water flow

- Take a 20 cm length of dialysis tubing that has been soaked in water and tie a knot tightly at one end.
- Place 3 cm^3 of a strong sugar solution in the tubing using a plastic syringe and add a small amount of coloured dye.
- Fit the tubing over the end of a length of capillary tubing and hold it in place with an elastic band. Push the capillary tubing into the dialysis tubing until the sugar solution enters the capillary.
- Now clamp the capillary tubing so that the dialysis tubing is totally covered by the water in the beaker, as shown in Figure 3.18.
- Watch the level of liquid in the capillary tubing over the next 10–15 minutes.



▲ **Figure 3.18** Demonstration of osmosis

Result

The level of liquid in the capillary tube rises.

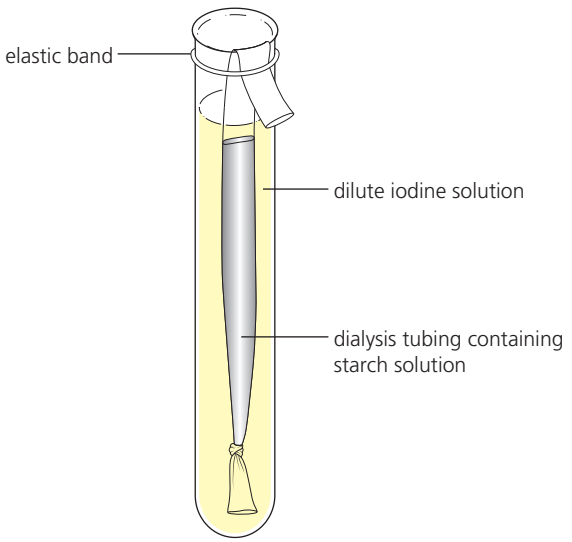
Interpretation

Water must be passing into the sugar solution from the beaker. This is what you would expect when a concentrated solution is separated from water by a partially permeable membrane.

A process like this may be involved in moving water from the roots to the stem of a plant.

5 Partial permeability

- Take a 15 cm length of dialysis tubing that has been soaked in water. Tie a knot tightly at one end.
- Use a dropping pipette to partly fill the tubing with 1% starch solution.
- Put the tubing in a test tube and hold it in place with an elastic band, as shown in Figure 3.19.
- Rinse the tubing and test tube under the tap to remove all traces of starch solution from the outside of the dialysis tube.
- Fill the test tube with water and add a few drops of iodine solution to colour the water yellow.
- Leave for 10–15 minutes.
- After this time, observe any changes in the solution in the test tube.



▲ **Figure 3.19** Experiment to demonstrate the effect of a partially permeable membrane

Result

The starch inside the dialysis tubing goes blue but the iodine solution outside stays yellow or brown.

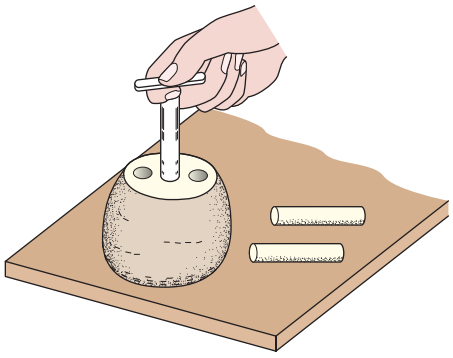
Interpretation

The blue colour is normal for the reaction that takes place between starch and iodine solution. This is used as a test for starch (see Chapter 4). The results show that iodine molecules have passed through the dialysis tubing into the starch, but the starch molecules have not moved out of the tubing into the iodine solution. The dialysis tubing is partially permeable because of its pore size. Starch molecules are very large and probably cannot get through the pores. Iodine molecules are much smaller and can get through.

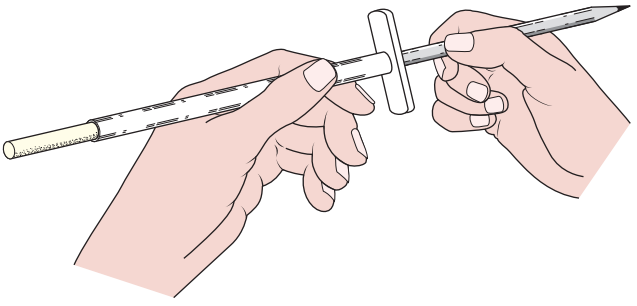
Note: This experiment shows that movement of water is not necessarily involved, and the pore size of the membrane makes it truly partially permeable with respect to iodine solution and starch.

6 The effects of water and sugar solution on potato tissue

- Push a No.4 or No.5 cork borer into a large potato.
  Caution: Do not hold the potato in your hand; use a board as in Figure 3.20(a).
- Push the potato tissue out of the cork borer using a pencil, as in Figure 3.20(b). Prepare a number of potato cylinders in this way and choose the two longest. (They should be at least 50 mm long.) Cut these two accurately to the same length, e.g. 50, 60 or 70 mm. Measure carefully.
- Label two test tubes A and B and place a potato cylinder in each. Cover the potato tissue in tube A with water; cover the tissue in B with a 20% sugar solution.
- Leave the tubes for 24 hours.
- After this time, remove the cylinder from tube A and measure its length. Notice also whether it is firm or flabby. Repeat this for the potato in tube B but rinse it in water before measuring it.



(a) place the potato on a board



(b) push the potato cylinder out with a pencil

▲ **Figure 3.20** Obtaining cylinders of potato tissue

Result

The cylinder from tube A should have increased in length and feel firm. The cylinder from tube B should have decreased in length and feel flabby.

Interpretation

The cells of the potato in tube A have absorbed water by osmosis, causing an increase in the length of the potato cylinder.

In tube B, the sugar solution is more concentrated than the cell sap of the potato cells, so these cells have lost water by osmosis. As a result, the potato cylinder has become flabby and shorter.

An alternative to measuring the potato cores is to weigh them before and after the 24 hours' immersion in water or sugar solution. The core in tube A should gain mass and that in tube B should lose mass. It is important to blot the cores dry with a paper towel before weighing them.

Whichever method is used, the changes may be quite small. So it is a good idea to collect the results of the whole class. An increase in length of 1 or 2 mm might be due to an error in measurement, but if most of the class record an increase in length, then experimental error is unlikely to be the cause.

7 The effects of varying the concentration of sucrose solution on potato tissue

- Push a No.4 or No.5 cork borer into a large potato.
  Caution: Do not hold the potato in your hand; use a board as in Figure 3.20(a).
- Push the potato tissue out of the cork borer using a pencil, as in Figure 3.20(b). Prepare six potato cylinders in this way and cut them all to the same length. (They should be at least 50 mm long.) Measure them carefully.
- Label six test tubes with the concentration of **sucrose** solution in them (e.g. 0.0 mol dm^{-3}, 0.2 mol dm^{-3}, 0.4 mol dm^{-3}, 0.6 mol dm^{-3}, 0.8 mol dm^{-3} and 1.0 mol dm^{-3}) and place them in a test-tube rack.
- Add the same volume of the correct sucrose solution to each test tube.
- Weigh a cylinder of potato, record its mass and place it in the first test tube. Repeat until all the test tubes have been set up.
- Leave the tubes for at least 30 minutes.
- After this time, remove the potato cylinder from the first tube, surface dry the potato and re-weigh it. Notice also whether it is firm or flabby. Repeat this for the other potato cylinders.
- Calculate the change in mass and the percentage change in mass for each cylinder.

$$\text{Percentage change in mass} = \frac{(\text{change in mass})}{(\text{mass at start})} \times 100$$

- Plot the results on a graph with sucrose concentration on the horizontal axis and percentage change in mass on the vertical axis.

Note: There will be negative as well as positive percentage changes in mass, so your graph axes will have to allow for this.

Result

The cylinders in the weaker sucrose solutions will have gained mass and feel firm. One of the cylinders may have shown no change in mass. The cylinders in the more concentrated sucrose solutions will have lost mass and feel limp.

Interpretation

If the potato cells are in a solution that has a lower concentration than the solution in the cell vacuoles, water will move into the cells by osmosis. The potato will increase in mass because of the extra water it has gained. The cells swell up and this makes the potato feel firm.

If the potato cells are in a solution that has a higher concentration than the solution in the cell vacuoles, water will move out of the cells by osmosis. The potato will decrease in mass because it has lost water. The cell vacuoles are no longer full of fluid and this makes the potato feel limp.

Practical work questions

9 In experiment 4 (Figure 3.18), what do you think would happen in these cases?
- **a** A much stronger sugar solution was placed in the cellulose tube.
- **b** The beaker contained a weak sugar solution instead of water.
- **c** The sugar solution was in the beaker and the water was in the cellulose tube?

10 In experiment 4, the column of liquid accumulating in the capillary tube applies a steadily increasing pressure on the solution in the dialysis tubing. If a very long capillary is used, when would you expect the net flow of water from the beaker into the dialysis tubing to stop?

11 For experiment 5, explain how the iodine solution got into the dialysis tubing.

12 For experiment 5, suggest what would happen if you did not rinse the dialysis tubing thoroughly before placing it in the test tube.

13 For experiment 6, explain why the potato cylinder in test tube A increased in length.

14 For experiment 6, suggest two safety precautions you need to take when carrying out this experiment.

15 Use data from your graph in experiment 7 to describe and explain the effect of changing concentration of sucrose on potato tissue.

If you do not have your own data, use the information in the table below to plot a graph first.

concentration of sucrose solution/mol dm^{-3}	percentage change in mass
0.0	+3.3
0.2	−2.5
0.4	−8.3
0.6	−10.0
0.8	−10.8
1.0	−12.5

8 Osmosis and turgor

- Take a 20 cm length of dialysis tubing that has been soaked in water and tie a knot tightly at one end.
- Place 3 cm^3 of a strong sugar solution in the tubing using a plastic syringe (Figure 3.21(a)) and then knot the open end of the tube (Figure 3.21(b)). The partly filled tube should be quite floppy (Figure 3.21(c)).
- Place the tubing in a test tube of water for 30–45 minutes.
- After this time, remove the dialysis tubing from the water and note any changes in how it looks or feels.

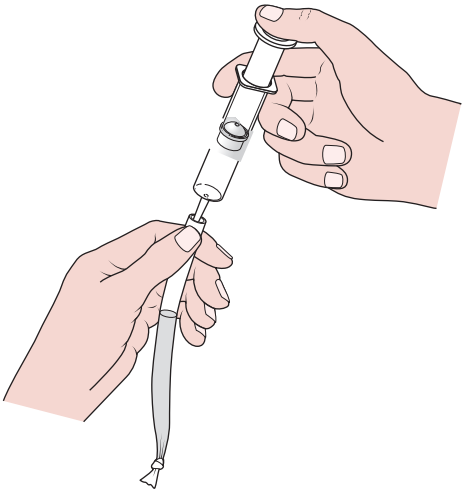
Result

The tubing will become firm, swollen by the solution inside.

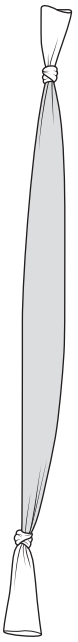
Interpretation

The dialysis tubing is partially permeable and the solution inside has fewer free water molecules than outside. So, water has diffused in and increased the volume and the pressure of the solution inside.

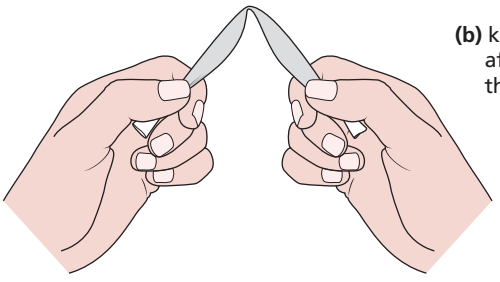
This is a simple model of what is thought to happen to a plant cell when it becomes turgid. The sugar solution is like the cell sap and the dialysis tubing is like the cell membrane and cell wall together.



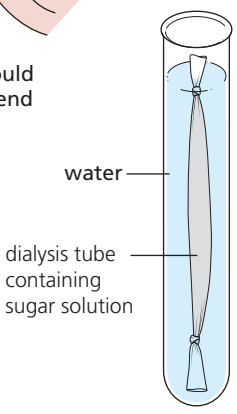
(a) place 3cm^3 sugar solution in the dialysis tube



(b) knot tightly, after expelling the air bubbles



(c) the partly filled tube should be flexible enough to bend



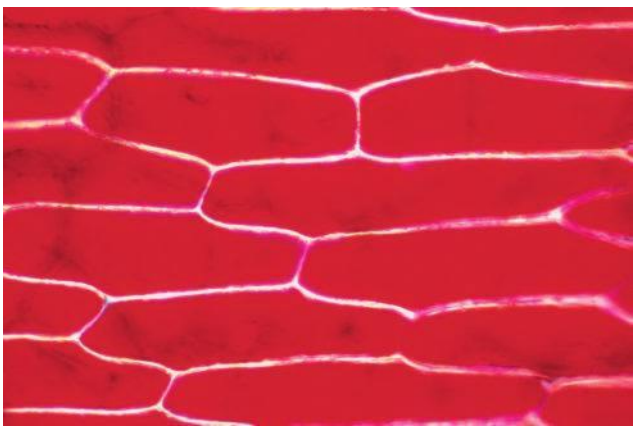
▲ **Figure 3.21** Experiment to model turgor in a plant cell

9 Plasmolysis

- Peel a small piece of epidermis (the outer layer of cells) from a red area of a rhubarb stalk (see Figure 1.12(c) on page 8).
- Place the epidermis on a slide with a drop of water and cover with a cover-slip (see Figure 1.12(b)).
- Put the slide on a microscope stage and find a small group of cells.
- Place a 30% solution of sugar at one edge of the cover-slip with a pipette. Move the solution under the cover-slip by placing a piece of blotting paper on the opposite side.
- Study the cells you identified under the microscope and watch for any changes in their appearance.

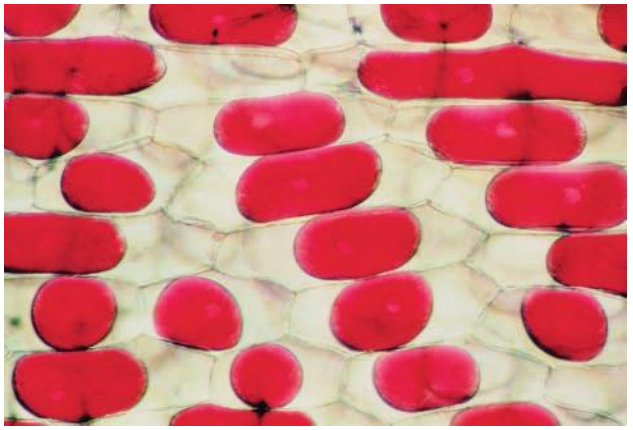
Result

The red cell sap will appear to get darker and shrink, pulling the cytoplasm away from the cell wall and leaving clear spaces. (It is not possible to see the cytoplasm, but its presence can be assumed because the red cell sap seems to have a distinct outer boundary where it has separated from the cell wall.) Figure 3.22 shows the turgid and plasmolysed cells.



(a) Turgid cells (×100). The cells are in a strip of epidermis from a rhubarb stalk. The cytoplasm is pressed against the inside of the cell wall by the vacuole.

▲ **Figure 3.22** Demonstration of plasmolysis in rhubarb cells

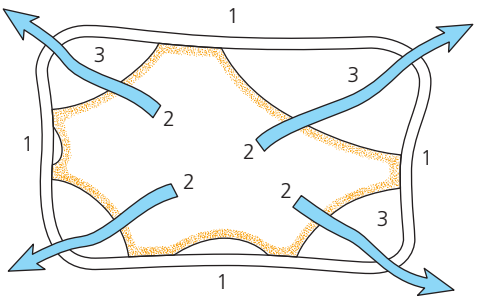


(b) Plasmolysed cells (×100). The same cells as they appear after treatment with sugar solution. The vacuole has lost water by osmosis, shrunk and pulled the cytoplasm away from the cell wall.

▲ **Figure 3.22** Demonstration of plasmolysis in rhubarb cells (continued)

Interpretation

The interpretation in terms of osmosis is given in Figure 3.23. The cells are plasmolysed.



1 the solution outside the cell is more concentrated than the cell sap
2 water diffuses out of the vacuole
3 the vacuole shrinks, pulling the cytoplasm away from the cell wall, leaving the cell flaccid

▲ **Figure 3.23** Plasmolysis

The plasmolysis can be reversed by drawing water under the cover-slip in the same way that you drew the sugar solution under. It may need two or three lots of water to move out all the sugar. If you watch a group of cells, you should see their vacuoles expanding to fill the cells once again.

Rhubarb is used for this experiment because the coloured cell sap shows up. If rhubarb is not available, the epidermis from a red onion scale can be used.

10 The effects of varying the concentration of sucrose solution on potato tissue

Refer back to experiment 7.

Interpretation

If the cells of the potato have absorbed water by osmosis, there will be an increase in the mass of the potato cylinder. This happens when the external solution has a higher water potential than the water potential inside the potato cells. (The sucrose solution is less concentrated than the contents of the potato cells.) Water molecules move into each cell through the cell membrane. The water molecules move from a higher water potential to a lower water potential. The cells become turgid, so the cylinder feels firm.

If the cells of the potato have lost water by osmosis, there will be a decrease in mass of the potato cylinder. This happens when the external solution has a lower water potential than the water potential inside the potato cells. (The sucrose solution is more concentrated than the contents of the potato cells.) Water molecules move out of each cell through the cell membrane. The water molecules move from a higher water potential to a lower water potential. The cells become plasmolysed or flaccid, so the cylinder feels flabby.

Practical work questions

16 a Which part of a plant cell do the parts of the model represent?
i) dialysis tube
ii) the contents of the dialysis tube.
b Explain how the process you have observed would be useful in a plant.

17 a Explain how a cell becomes plasmolysed.
b How could a plasmolysed cell be returned to full turgor?

18 Study your graph from experiment 7. Can you predict the sucrose concentration which would be the equivalent to the concentration of the cell sap in the potato cells?

19 Would you expect to get the same results if the potato cylinders had been boiled before the investigation? Explain your answer.

Active transport

FOCUS POINTS

- ★ What is active transport?
- ★ Why is active transport important for moving molecules or ions across membranes?

Key definitions

Active transport is the movement of molecules or ions into or out of a cell through a cell membrane from a region of their lower concentration to a region of their higher concentration against a concentration gradient, using energy released during respiration.

The importance of active transport

If diffusion was the only way a cell could take in substances, it would have no control over what went in or out. Anything that was more concentrated outside would diffuse into the cell even if it was harmful. Substances which the cell needed would diffuse out as soon as their concentration inside the cell increased above their concentration outside it. However, the cell membrane has a lot of control over the substances which enter and leave the cell.

In some cases, substances are taken into or removed from the cell against the concentration gradient. For example, plants need to absorb mineral ions from the soil, but these ions are in very dilute solution. Active transport allows the root hair cells of plant roots to take up mineral ions from this dilute solution against the concentration gradient. Again, chemical energy from respiration is converted into kinetic energy for movement of the ions.

Sodium ions may continue to pass out of a cell even though the concentration outside is greater than inside. The cells lining the small intestine take up glucose against a concentration gradient. The processes by which substances are moved against a concentration gradient are not fully understood. The processes may vary for different substances, but they are described as active transport.

Anything which interferes with respiration, like a shortage of oxygen or glucose, stops active transport happening. This shows that active transport needs a supply of energy from respiration.

Epithelial cells in the villi of the small intestine have the job of absorbing glucose against a concentration gradient. The cells contain large numbers of mitochondria in which respiration takes place. The chemical energy released is converted into kinetic energy for the movement of the glucose molecules. The same type of process happens in the cells of the kidney tubules for the reabsorption of glucose molecules into the bloodstream against their concentration gradient.

Going further

Controlled diffusion

Although for any one substance the rate of diffusion through a cell membrane depends partly on the concentration gradient, the rate is often faster or slower than expected. Water diffuses more slowly and amino acids diffuse more rapidly through a membrane than expected. In some cases, scientists think this happens because the ions or molecules can pass through the membrane through special pores. There may not be many of these pores, or they may be open or closed in different conditions.

In other cases, the movement of a substance can be speeded up by an enzyme working in the cell membrane. So, 'simple passive' diffusion, even of water molecules, may not be so simple or so passive where cell membranes are involved.

When a molecule gets inside a cell, there are many structures and processes which may move it from where it enters to where it is needed. Simple diffusion is unlikely to be the only way that this movement happens.

Test yourself

6 Suggest why a cell stops taking in substances by active transport which has been exposed to
- **a** high temperature
- **b** respiratory poison.

7 State which parts of a cell are responsible for
- **a** releasing energy for active transport across the cell membrane
- **b** controlling cell activities such as active transport
- **c** storing mineral ions which have passed through the cell membrane.

Revision checklist

After studying Chapter 3 you should know and understand the following:

- ✔ Diffusion is the random movement of molecules of liquid, gas or dissolved solid.
- ✔ The molecules of a substance diffuse from a region where they are very concentrated to a region where they are less concentrated.
- ✔ Kinetic energy of molecules and ions results in their diffusion.
- ✔ Substances may enter cells through the cell membrane by simple diffusion or active transport.
- ✔ The rate of diffusion is affected by surface area, temperature, concentration gradient and distance.
- ✔ Water has several roles as a solvent in organisms.
- ✔ Cell membranes are partially permeable, and cytoplasm and cell sap contain many substances in solution.
- ✔ Osmosis involves the net movement of water molecules from a region of higher water potential to a region of lower water potential through a partially permeable membrane.
- ✔ The meanings of the terms *turgid*, *turgor pressure*, *plasmolysis* and *flaccid*.
- ✔ The importance of water potential and osmosis in the uptake and loss of water by organisms.
- ✔ Osmosis maintains the pressure of water in plant cells to support the plant.
- ✔ Active transport involves the movement of substances against their concentration gradient.
- ✔ Active transport requires energy.
- ✔ Active transport is important as it allows movement of substances across membranes against a concentration gradient.

Exam-style questions

1 Diffusion, osmosis and active transport are processes involved in the movement of substances in a plant.
Complete the table by
a defining what each term means [4]
b giving one example of a substance moved by the process in the plant. [5]

name of process	definition	example of a substance moved by the process in the plant
diffusion		
osmosis		
active transport		

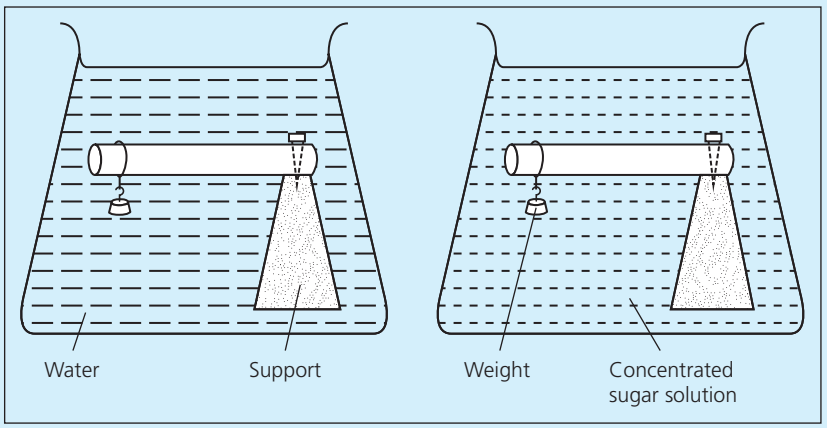
2 When a plant leaf is in daylight, its cells make glucose from carbon dioxide and water. The glucose is turned into starch straight away and stored in plastids. Glucose is soluble in water; starch is insoluble. With reference to osmosis, suggest why it is an advantage for the plant to convert the glucose to starch. [3]

3 When doing experiments with animal tissues they are usually bathed in Ringer's solution, which has a concentration like the concentration of blood or the fluid that surrounds cells. With reference to osmosis, explain why this is necessary. [2]

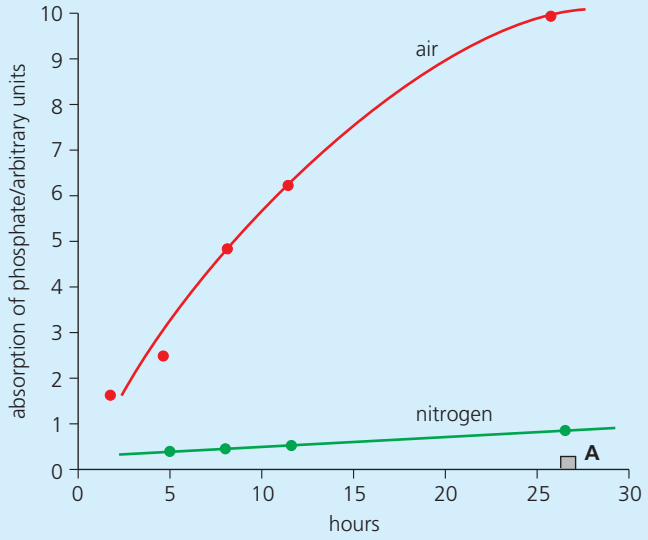
4 Explain why a dissolved substance reduces the number of 'free' water molecules in a solution. [2]

5 Some plant cells were placed on a microscope slide and covered with sugar solution, which was more concentrated than the sugar inside the cells.
a Describe what changes would happen in each of the following cell parts:
i) cell wall [1]
ii) cytoplasm [1]
iii) sap vacuole. [1]
b With reference to water potential gradient, explain how these changes occur. [2]
c **i)** State the differences between diffusion and active transport. [2]
ii) Give **one** example of each process in living organisms. [2]

6 The diagram shows a cylinder of potato tuber, with a weight attached, in a container of water. A second, identical cylinder of potato was set up in the same way but placed in a container of concentrated sugar solution. Both cylinders were left for 3 hours.
a Describe and explain in terms of water potential what would happen to
i) the potato in water [3]
ii) the potato in the concentrated sugar solution. [3]
b State the name of the process involved in causing any changes to the appearance of the cylinders. [1]
c Root hair cells are involved in taking up water and mineral ions from the surrounding soil. State how the processes of taking up these substances are different. [2]



7 The graph shows the absorption of phosphate ions by the roots of a beech plant when kept in an atmosphere of air or nitrogen. **A** represents the concentration of phosphate in external solution.



a State which plant cells absorb the phosphate ions. [1]

b Describe the absorption of phosphate ions by the beech plant

i) in an atmosphere of air [2]

ii) in an atmosphere of nitrogen. [2]

c Suggest what process is involved in the absorption of phosphate ions. Explain your answer. [3]

4 Biological molecules

Focus

In the last chapter, you learned about diffusion, osmosis and active transport and their importance in moving materials in and out of cells. You will now understand how living organisms make use of these processes and the problems that can be faced by cells. In this chapter you will develop a knowledge of the main nutrients and substances that make up living things, and how you can use biochemical tests for their presence in food. Which foods do you think are good sources of carbohydrate, lipids and proteins? Will the food tests you carry out confirm this? DNA is also a key biological molecule. What is its structure and what elements are present in it?

Biological molecules

FOCUS POINTS

- ★ What are the chemical elements that make up carbohydrates, lipids, proteins and DNA?
- ★ What are larger molecules made up of?
- ★ What are the chemical tests for the presence of starch, glucose and maltose, proteins and lipids?

Carbon is an element present in all biological molecules. Carbon atoms can join to form chains or ring structures, so biological molecules can be very large. They are often built of repeating sub-units (monomers). Oxygen and hydrogen are other elements that are always present. Nitrogen is sometimes present. When molecules are made of long chains of monomers held together by chemical bonds, they are called polymers (poly means 'many'). Examples are **polysaccharides** (chains of single sugar units like glucose), proteins (chains of amino acids) and DNA (chains of units called **nucleotides**, see Chapter 17). Molecules built of lots of small units often have different properties from their sub-units. This makes them suitable for specific jobs in living things. For example, glucose is very soluble and has no strength, but cellulose (a large molecule made of glucose units) is insoluble and very tough – ideal for making cell walls around plant cells.

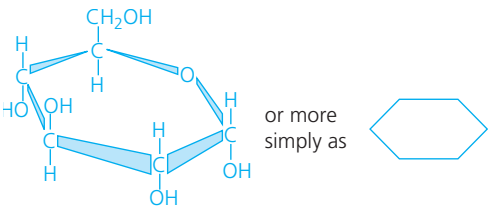
Cells need chemical substances to make new cytoplasm and to release energy, so, the organism must take in food to supply the cells with these substances. However, it is not as simple as this; most cells have special jobs (Chapter 1) and so have different needs.

All cells need water, oxygen, mineral ions and food substances though, and all cells are made up of water, proteins, lipids, carbohydrates, mineral ions and vitamins, or forms of them.

Carbohydrates

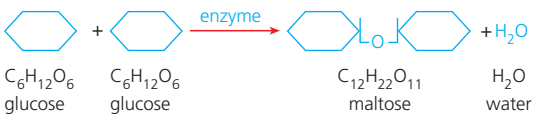
These may be simple, soluble sugars or complicated materials like starch and cellulose, but all carbohydrates contain carbon, hydrogen and oxygen only. A common simple sugar is glucose, which has the chemical formula $C_6H_{12}O_6$.

The glucose molecule is often in the shape of a ring, shown as:



▲ **Figure 4.1** Glucose molecule showing ring structure

Two molecules of glucose can be joined to make a molecule of **maltose**, $C_{12}H_{22}O_{11}$ (Figure 4.2).



▲ **Figure 4.2** Formation of maltose

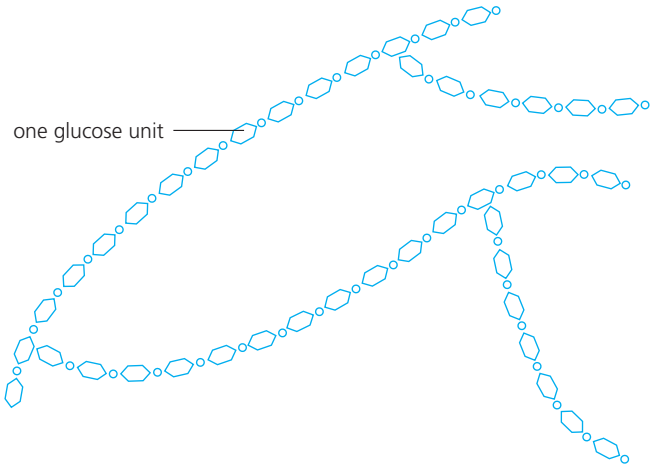
Sugars with a single carbon ring are called monosaccharides (e.g. glucose and fructose). Those sugars with two carbon rings in their molecules are called disaccharides (e.g. maltose and sucrose). Mono- and disaccharides are readily soluble in water.

Glycogen (Figure 4.3) is a large molecule made up of glucose molecules. It is a food storage substance in many animal cells.

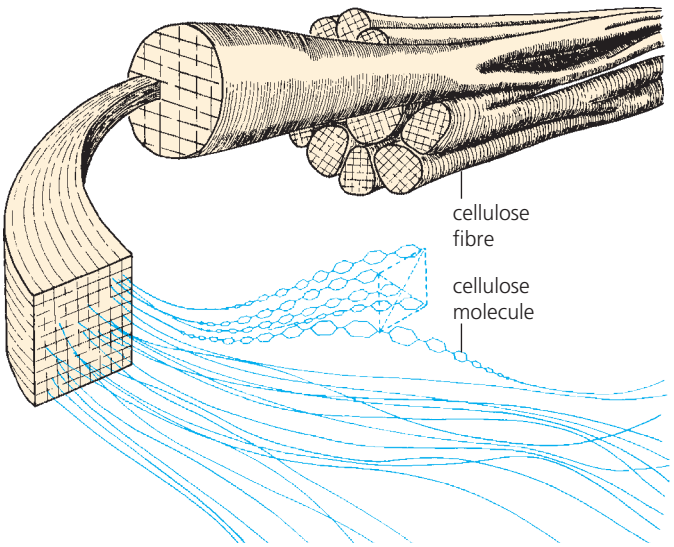
The starch molecule is made up of hundreds of glucose molecules joined to make long chains. Starch is an important storage substance in plant cells.

Cellulose is made of even longer chains of glucose molecules. The molecules in the chain are grouped together to make microscopic **fibres**, which are laid down in layers to make the cell wall in plant cells (Figures 4.4 and 4.5).

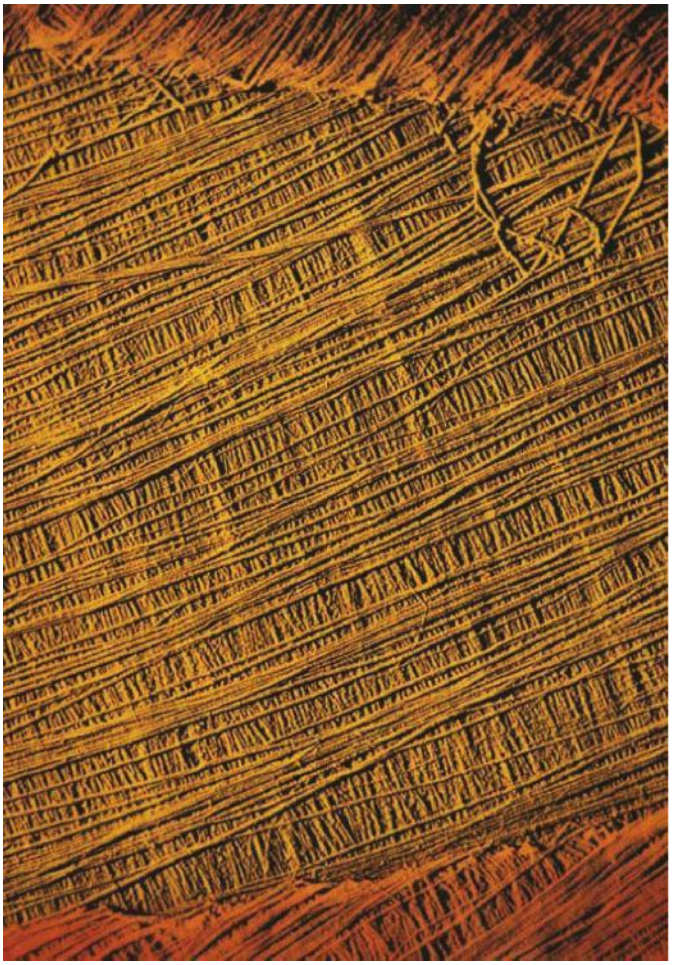
Glycogen, starch and cellulose are not very soluble in water.



▲ **Figure 4.3** Part of a glycogen molecule



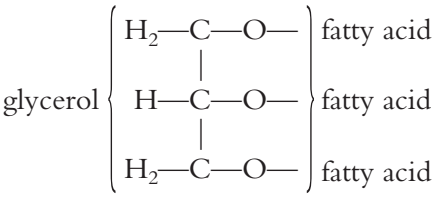
▲ **Figure 4.4** Cellulose. Plant cell walls are made of long, interconnected cellulose fibres. These are large enough to be seen with the electron microscope. Each fibre is made up of many long-chain cellulose molecules



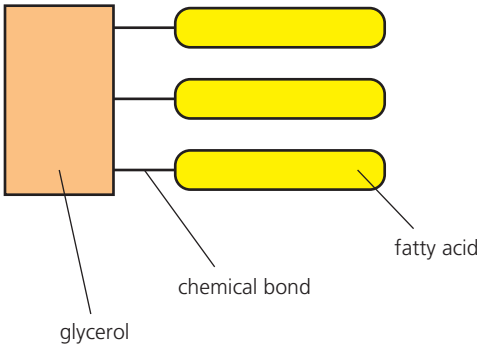
▲ **Figure 4.5** Scanning electron micrograph of a plant cell wall (×20 000) showing the cellulose fibres

Lipids

Lipids are fats and oils. Fats are a solid form of this group of molecules. When lipids are liquid they are known as oils. Lipids are made from carbon, hydrogen and oxygen only. A molecule of lipid is made up of three molecules of an organic acid, called a **fatty acid**, joined with one molecule of **glycerol**.



Drawn simply, lipid molecules can be shown as in Figure 4.6.



▲ **Figure 4.6** Lipid molecule

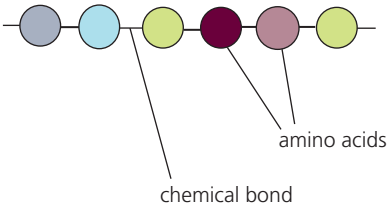
Lipids form part of the cell membrane and the internal membranes of the cell like the nuclear membrane. Droplets of lipid form a source of energy when stored in the cytoplasm.

Proteins

Some proteins are part of structures in the cell, for example, the cell membranes, the mitochondria, ribosomes and chromosomes.

There is another group of proteins called enzymes. Enzymes are present in the membrane systems, in the mitochondria, in special vacuoles and in the fluid part of the cytoplasm. Enzymes control the chemical reactions that keep the cell alive (see Chapter 5).

Although there are many different types of protein, they all contain carbon, hydrogen, oxygen and nitrogen, and many contain sulfur. Their molecules are made up of long chains of simpler chemicals called amino acids (Figure 4.7).



▲ **Figure 4.7** Protein molecule (part of)

There are about 20 different amino acids in animal proteins. These include alanine, leucine, valine, glutamine, cysteine, glycine and lysine. A small protein molecule can be made up from a chain consisting of a hundred or more amino acids, for example, glycine–valine–valine–cysteine–leucine–glutamine–, etc. Each type of protein has its amino acids arranged in a special sequence.

DNA

A DNA molecule contains the elements carbon, hydrogen, oxygen, nitrogen, phosphorus and sometimes sulfur. It is made up of long chains of nucleotides, formed into two strands. A nucleotide is made up of a 5-carbon sugar molecule joined to a phosphate group ($-PO_3$) and an organic **base** (Figure 17.5 on page 286).

Going further

Synthesis and conversion in cells

Cells can build up (synthesise) or break down their proteins, fats and carbohydrates, or change one to another. For example, animal cells synthesise glycogen from glucose by joining glucose molecules together (Figure 4.3); plant cells synthesise starch and cellulose from glucose. All cells can make proteins from amino acids. They can also build up lipids from glycerol and fatty acids. Animal cells can change carbohydrates to lipids, and lipids to carbohydrates; they can also change proteins to carbohydrates, but they cannot make proteins unless they are supplied with amino acids. However, plant cells can make their own amino acids using sugars and mineral ions. The cells in the green parts of plants can even make glucose starting from only carbon dioxide and water (see 'Photosynthesis' in Chapter 6).

▼ **Table 4.1** Summary of the main nutrients

Nutrient	Elements present	Examples	Sub-units
carbohydrate	carbon, hydrogen, oxygen	starch, glycogen, cellulose, sucrose	glucose
lipid	carbon, hydrogen, oxygen (but lower oxygen content than carbohydrates)	vegetable oils, e.g. olive oil; animal fats, e.g. cod liver oil, waxes	fatty acids and glycerol
protein	carbon, hydrogen, oxygen, nitrogen, sometimes sulfur or phosphorus	enzymes, muscle, haemoglobin, cell membranes	amino acids (about 20 different forms)

Test yourself

1 State which type of molecule contains the following sub-units:
   a amino acids
   b fatty acids
   c glucose
   d glycerol
   e nucleotide.

2 Which nutrients contain nitrogen atoms?

3 Explain why there are many more different proteins than carbohydrates.

4 a What do the chemical structures of carbohydrates and lipids have in common?
   b How do their chemical structures differ?

Practical work

Safety

- Eye protection must be worn.
- Take care using iodine solution – it can stain skin and clothes.
- Take care handling hot water.

Food tests

1 Test for starch

- Shake a small amount of starch powder in a test tube with some warm water. This will make a starch suspension.
- Add 3 or 4 drops of iodine solution. A blue-black colour should be produced.
  Note: It is also possible to use iodine solution to test for starch in leaves, but a different method is used (see Chapter 6).

2 Test for reducing sugar (e.g. glucose, maltose)

- Heat 2 cm^3 depth of glucose solution with an equal volume of **Benedict's solution** in a test tube. Place the test tube in a beaker of boiling water to heat it (see Figure 4.8), or warm it in a water-bath. The solution will change from clear blue to cloudy green, then yellow and finally to a red precipitate (deposit) of copper(I) oxide, because glucose is a **reducing sugar**.

3 Test for protein (biuret test)

- Place 2 cm^3 depth of 1% albumen solution (the protein of egg white) in a test tube. Add 2 cm^3 dilute (0.4 mol dm^{-3}) sodium hydroxide (***CARE:*** this solution is an irritant), followed by 2 cm^3 1% copper sulfate solution. This is the biuret test. A purple colour indicates protein. If you run the copper sulfate into the test tube without mixing, you will see a violet halo where the two liquids touch each other.

4 Test for lipid

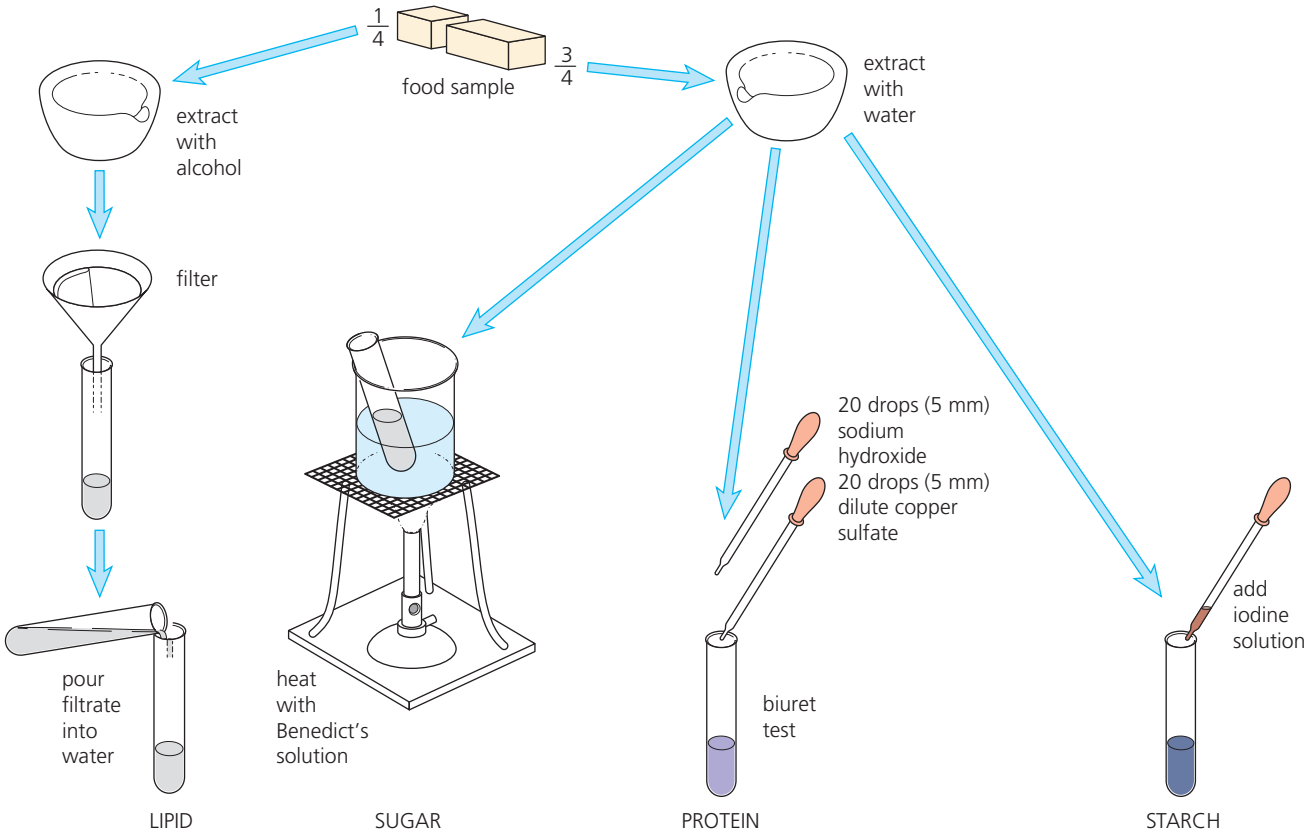
- Shake two drops of cooking oil with about 5 cm^3 ethanol in a dry test tube until the lipid dissolves.
- Pour this solution into a test tube containing a few cm^3 water. A milky white emulsion will form. This shows that the solution contained some fat or oil.

Safety

- Do not attempt these tests if you have an allergy to any of the foods being tested, e.g. peanuts.

Application of the food tests

The tests can be used on samples of food like milk, potato, cassava, raisins, onion, beans, egg-yolk or peanuts to find out what food materials are present. Crush the solid samples in a mortar and shake with warm water to get a solution or suspension. Pour small amounts of the watery mixture into several test tubes. Test the samples for starch, glucose or protein as described above. To test for lipids, the food must first be crushed in ethanol, not water, and then filtered. Pour the clear filtrate into water. A milky colour indicates the presence of lipids.



▲ **Figure 4.8** Experiment to test foods for different nutrients

Practical work questions

1 A test on a food gives the following results:
- It turns blue-black with iodine solution.
- It turns milky with ethanol.

What nutrients does the food contain? Explain your answer.

2 Describe what safety precautions you would take when carrying out a food test for
a protein
b maltose.
Explain your answers.

Revision checklist

After studying Chapter 4 you should know and understand the following:

- ✔ Living matter is made up of several important types of molecules, including proteins, lipids and carbohydrates.
- ✔ Carbohydrate, protein, lipid and DNA molecules contain carbon, hydrogen and oxygen atoms. Proteins also contain nitrogen and sometimes phosphorus or sulfur. DNA also contains phosphorus.
- ✔ Carbohydrates are made from simple sugar units, often glucose.
- ✔ Carbohydrates are used as an energy source; glycogen and starch make good storage molecules. Cellulose gives plant cell walls their strength.
- ✔ Lipids are made from fatty acids and glycerol.
- ✔ Proteins are made of chains of amino acids.
- ✔ DNA is made up of two strands of nucleotides.
- ✔ Membranes outside and inside the cell are made of proteins and lipids.
- ✔ Food tests are used to identify the main biological molecules.

Exam-style questions

1 **a** State what chemical structures carbohydrates and lipids have in common. [2]

b Describe how their chemical structures differ. [3]

2 Protein and carbohydrate molecules have some features in common and some features which make them different.

a State **one** feature which they both have. [1]

b State **two** features which make them different. [2]

3 **a** State the name of the group of nutrients to which cellulose, glycogen and starch all belong. [1]

b Complete the table by stating one function of each of the molecules and where they are found in a cell. [6]

nutrient molecule	function of nutrient molecule	where the nutrient molecule is found in a cell
cellulose		
glycogen		
starch		

4 Three types of fruit juice, A, B and C, were tested.

a The fruit juices tasted sweet. Describe how you would test them to see if they contained glucose. [3]

b State the precautions you would take when carrying out this food test. [3]

c State the colour change you would observe if the fruit juice did contain glucose. [1]

5 Complete the table to compare carbohydrates, lipids and proteins. [6]

nutrient	elements present	sub-unit(s) present
carbohydrate		
lipid		
protein		

6 The following is a list of nutrient molecules and their sub-units:

amino acid	cellulose	lipid
fatty acid	glucose	glycerol
glycogen	protein	starch

State which molecules

a are polymers [4]

b are carbohydrates [4]

c are sub-units of larger molecules. [4]

5 Enzymes

Focus

In the previous chapter you developed your knowledge and understanding of biological molecules. You discovered the importance of carbon atoms in their formation. You now know that the properties of key biological molecules make them suitable for many different uses in the organism. For example, some protein molecules form enzymes. In this chapter you will find out about the properties of enzymes and how they work. You will meet the terms *complementary shape* and *active site*. In what ways are enzymes similar to, and different from, catalysts? Why does an enzyme only work on one chemical? Once you understand how enzymes work, you will be able to answer these questions.

FOCUS POINTS

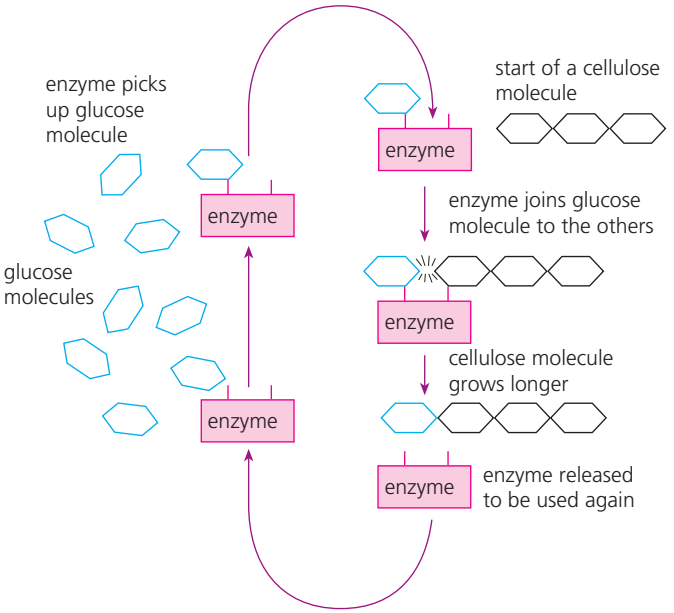
- ★ What is a catalyst?
- ★ What are enzymes and why are they important?
- ★ How do enzymes catalyse reactions?
- ★ Why are enzymes specific to only one reaction?
- ★ What are the effects of temperature and pH on enzyme activity and why?

Key definitions

A **catalyst** is a substance that increases the rate of a chemical reaction and is not changed by the reaction.

Enzymes are proteins that function as **biological catalysts** and are involved in all metabolic reactions.

Enzymes are proteins that act as catalysts. They are made in all living cells. Enzymes, like all catalysts, can be used repeatedly because they are not used up during the reaction. Also, only small amounts are needed to speed the reaction up (Figure 5.1). They are important because they control the reactions in the cell. They make sure that these reactions occur quickly enough for the cell to function.



▲ **Figure 5.1** Building up a cellulose molecule

Enzyme action

An enzyme-controlled reaction involves a **substrate**, an enzyme and a product. The substrate and product may be two or more different molecules:

$$\text{substrate} \xrightarrow{\text{enzyme}} \text{product}$$

The substance on which an enzyme works is called its substrate and the molecules produced are called the products. For example, the enzyme sucrase works on the substrate sucrose to produce the monosaccharide products glucose and fructose.

Enzymes are specific

Specificity simply means that an enzyme which normally works on one substrate will not act on a different one. Figure 5.2(a) shows how the shape of an enzyme can control what substrates it joins with. The enzyme in Figure 5.2(a) has a shape called the **active site**, which exactly fits the substrates on which it works but which will not fit the substrate in Figure 5.2(b). The shape of the active site of the enzyme molecule and the substrate molecule are said to be **complementary**. This model is called the 'lock and key' hypothesis. The enzyme molecule is the lock and the substrate (molecules A and B in Figure 5.2(a)) is the key. For example, an enzyme which breaks down starch to maltose will not also break down proteins to amino acids.

In addition, if a reaction takes place in stages, such as:

starch $\longrightarrow$ maltose (stage 1)
maltose $\longrightarrow$ glucose (stage 2)

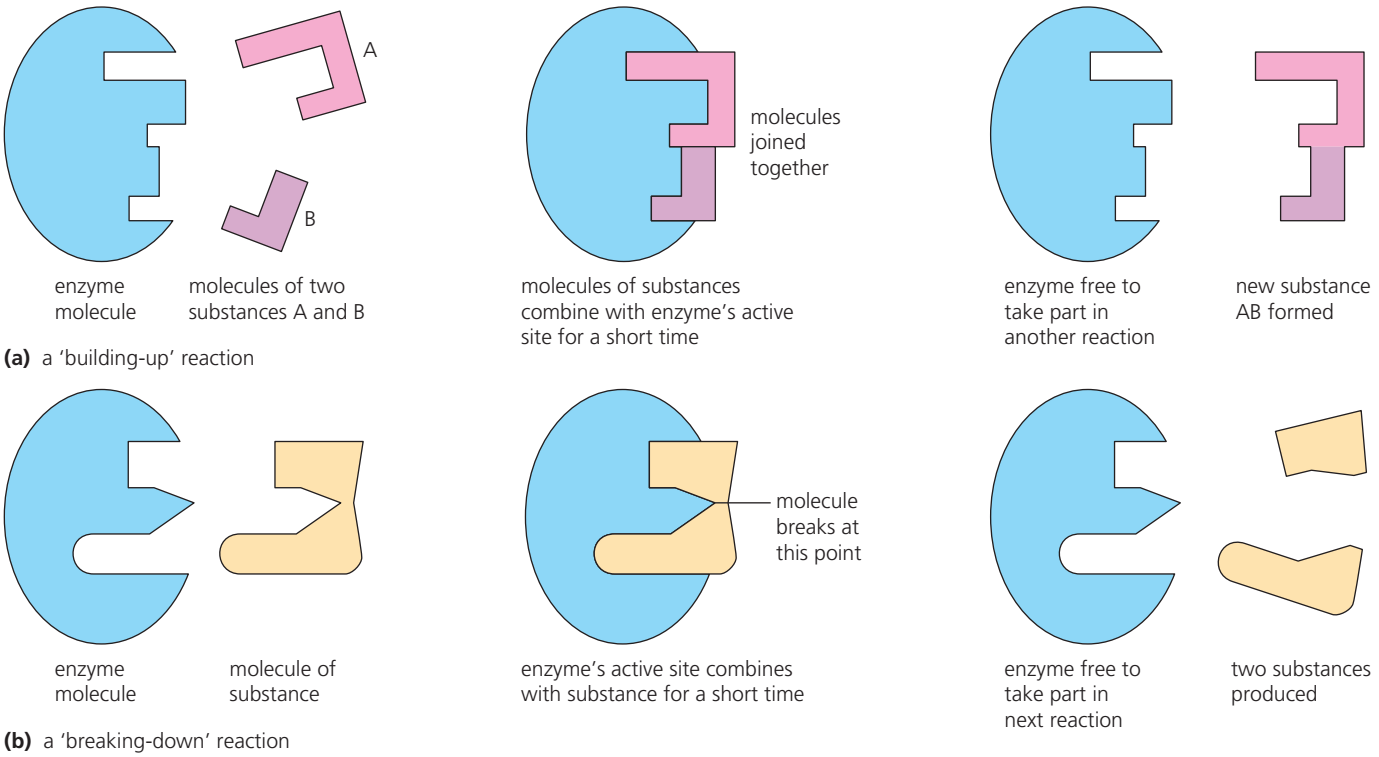
a different enzyme is needed for each stage. The names of enzymes usually end with -ase and they are named according to the substrate on which they work or the reaction which they speed up. For example, an enzyme that works on proteins may be called a **protease**; one that removes hydrogen from a substance is a dehydrogenase.

When the enzyme joins with the substrate, an **enzyme–substrate complex** is formed temporarily. The product (substance AB in Figure 5.2(a)) is released from the enzyme's active site and the enzyme is then free to repeat the reaction with more substrate molecules. Figure 5.2(b) shows an enzyme speeding up a chemical change, but this time the molecule of a substance is split into smaller molecules. Again, when the enzyme joins with the substrate, an enzyme–substrate complex is formed temporarily.

Molecules of the two substances can combine without the enzyme being present, but the process would be very slow (it could take hours or days to happen without the enzyme: too slow to keep an organism alive). By bringing the substances close together, the enzyme molecule makes the reaction take place much more rapidly. The process can be extremely fast: catalase, a very common enzyme found in most cells, can break down 40 000 molecules of hydrogen peroxide every second! A complete chemical reaction takes only a few seconds when the right enzyme is present.

Try chewing a piece of bread but keep it in your mouth without swallowing it. Eventually you should detect the food tasting sweeter, as maltose sugar is formed. If starch is mixed with water, it will break down very slowly to sugar. The process takes years. In your saliva there is an enzyme called **amylase**. This can break down starch to sugar in minutes or seconds. In cells, many of the enzymes are helping to break down glucose to carbon dioxide and water to release energy (Chapter 10).

As well as enzymes being responsible for joining two substrate molecules together, like two glucose molecules to form maltose, they can also make long chains. For example, hundreds of glucose molecules can be joined, end to end, to make a long molecule of starch. This is stored in the plastid of a plant cell. The glucose molecules can also be built up into a molecule of cellulose, to be added to the cell wall. Protein molecules are built up by enzymes, which join tens or hundreds of amino acid molecules. These proteins are added to the cell membrane, to the cytoplasm or to the nucleus of the cell. They may also become the proteins that work as enzymes.



▲ **Figure 5.2** The lock and key hypothesis for enzyme action

Figure 5.2 shows the lock and key hypothesis. This hypothesis suggests that the shape of an enzyme's active site is complementary to the substrates on which it works.

Effects of temperature and pH

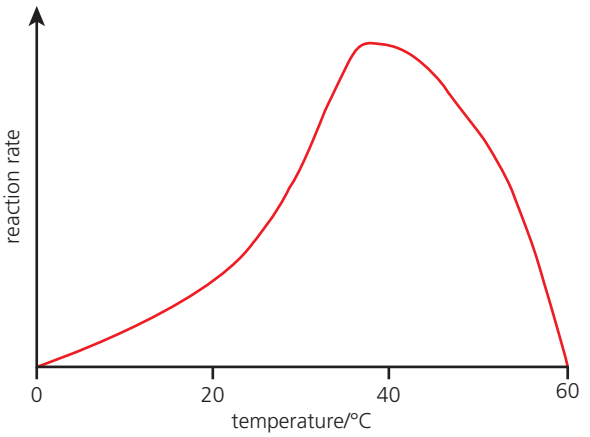
Enzymes and temperature

A rise in temperature increases the rate of most chemical reactions; a fall in temperature slows them down. Figure 5.3 shows the effect of temperature on an enzyme-controlled reaction.

Usually, a rise of 10 °C will double the rate of an enzyme-controlled reaction in a cell, up to an **optimum** temperature of about 37 °C (body temperature). This is because the enzyme and substrate molecules are constantly moving, using **kinetic energy**. The reaction only happens when the enzyme and substrate molecules collide with each other. As the temperature is increased, the molecules gain more kinetic energy, so they move faster and there is a greater chance of **collisions** happening. So, the rate of reaction increases.

Above the optimum temperature (about 50 °C) the molecules gain even more kinetic energy, but the reaction will slow down. This is because enzyme molecules are proteins. Protein molecules start to lose their shape at higher temperatures, so the shape of the active site changes. As a result, although there are more collisions due to the molecules having greater kinetic energy, the number of effective collisions reduces. Substrate molecules cannot fit together with the enzyme, stopping the reaction.

Not all the enzyme molecules are affected straight away, so the reaction does not suddenly stop; it is a gradual process as the temperature increases above 37 °C. **Denaturation** is a permanent change in the shape of the enzyme molecule. Once it has happened, the enzyme will not work anymore, even if the temperature is reduced below 37 °C.



▲ **Figure 5.3** Graph showing the effect of temperature on the rate of an enzyme-controlled reaction

This is one of the reasons why organisms may be killed by continued exposure to high temperatures. The enzymes in their cells are denatured and the chemical reactions happen too slowly to keep the organism alive.

Egg white is a protein called albumin. When it is heated, its molecules change shape. The egg white goes from a clear, runny liquid to a white solid. It cannot be changed back again. The egg white protein, albumen, has been denatured by heat.

Proteins make enzymes and many of the structures in the cell. So, if they are denatured the enzymes and the cell structures will stop working. The cell will die. Whole organisms may stay alive for a time above 50 °C. This depends on the temperature, the period of exposure and the proportion of the cells that are damaged.

One way to test if a substance is an enzyme is to heat it to boiling point. If it can still carry out its reactions after this, it cannot be an enzyme. This technique is used as a **control** (see 'Aerobic respiration' in Chapter 10) in enzyme experiments.

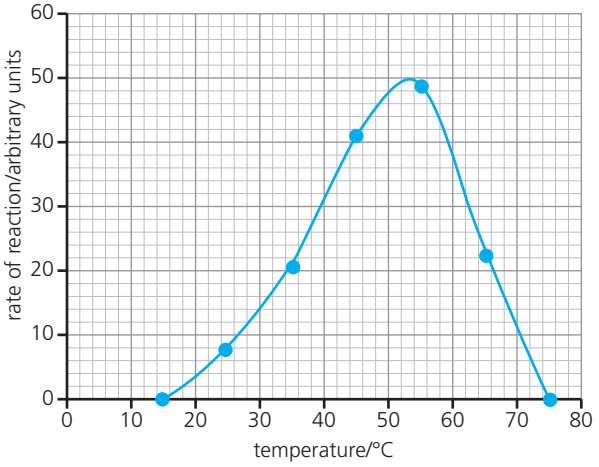
Scientists are starting to discover exceptions to the ways some enzymes are affected by high temperatures. There are some bacteria that live in an environment where the temperature is very high. Examples include species that live successfully in hot springs and around hydrothermal vents in the deep oceans (Figure 5.4). They have enzymes that are made of very stable proteins; their active sites are not deformed by temperatures above 50 °C. Scientists are very interested in these enzymes. They could be used in industrial applications where high temperatures are needed. For example, biological washing powders containing these enzymes could be used at a high temperature to remove difficult stains. Normally, the enzymes would be denatured.

Worked example

The table shows the results of an experiment investigating the effect of temperature on an enzyme reaction.

temp °C	rate of reaction/arbitrary units
15	0
25	8
35	21
45	41
55	49
65	23
75	0

1 a Plot a graph to show the effect of temperature on the rate of reaction.



Your graph should have the correct axis, with the independent **variable** (temp) as the *x*-axis and the dependent variable (rate of reaction) as the *y*-axis.

b What was the optimum temperature for this reaction?
55 °C. This is the temperature at which the rate of reaction is greatest.

c Calculate the percentage increase in reaction rate between 20 and 40 °C.

The rate at 20 °C = 4, the rate at 40 °C = 32
increase in rate = 32 – 4 = 28

percentage increase in reaction rate = increase/starting rate × 100

= 28/4 × 100 = 700%

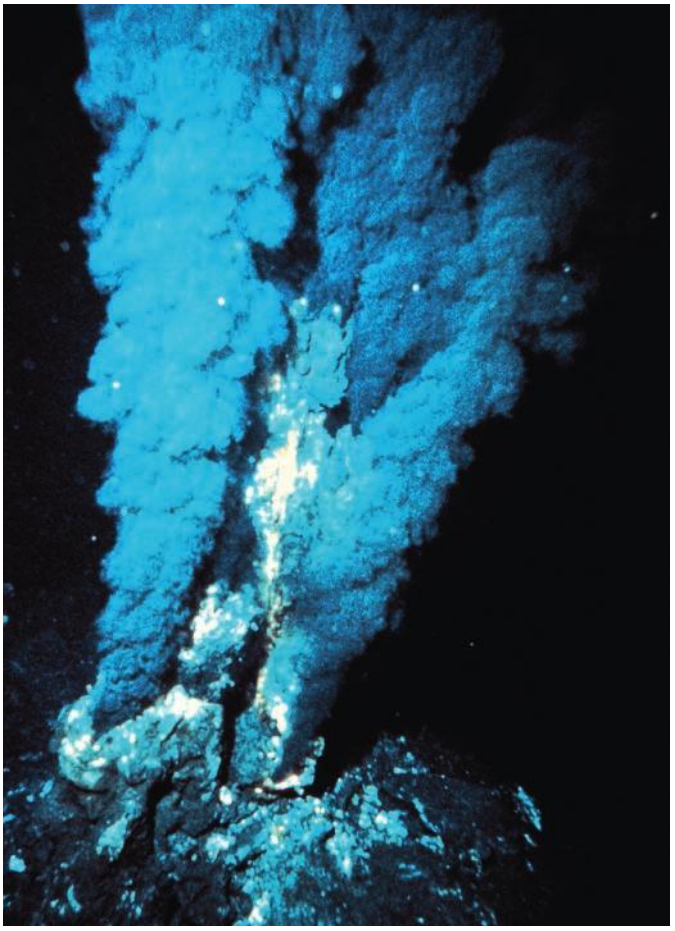
2 Calculate the percentage change in reaction rate between 60 and 70 °C.

At 60 °C the rate is 38, at 70 °C the rate is 11. The change in rate is 38 – 11 = 27.

The percentage change = 27/38 × 100 = 71%

3 a At which two temperatures was the reaction rate 30?
39 °C and 62 °C

b Suggest why the rate was the same even though the temperatures were different.
At 39 °C, the temperature is not quite the optimum, so the number of collisions is still limited, affecting the rate of reaction. At 62 °C, although the temperature is higher and so there will be more collisions, some of the enzyme molecules will have been denatured, so the rate of reaction is limited.



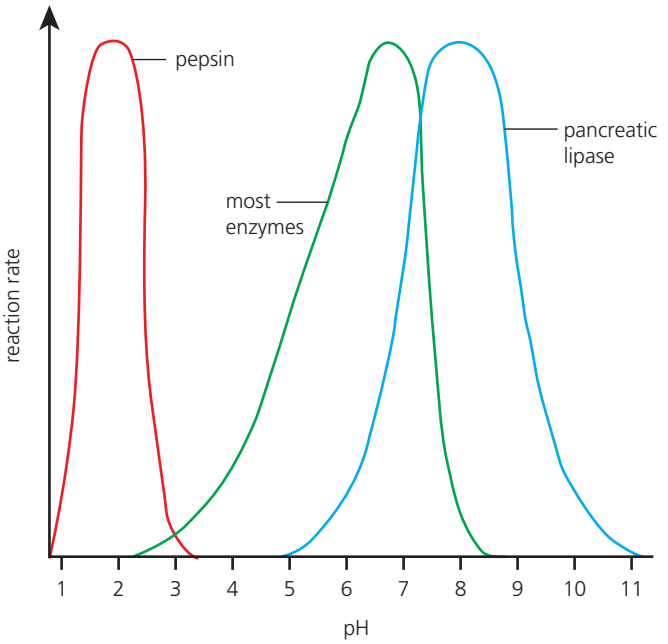
▲ **Figure 5.4** A hydrothermal vent, made as a result of volcanic activity on the sea floor. It is a good habitat for marine organisms, including bacteria and invertebrates, because the water is so rich in nutrients. However, these organisms need to survive at very high temperatures

Enzymes and pH

Acid or alkaline conditions can denature some enzymes. Most enzymes work best at a particular level of acidity or alkalinity (pH), as shown in Figure 5.5.

The protein-digesting enzyme in your stomach, for example, works well at an acidity of pH 2. At this pH, the enzyme amylase, from your saliva, cannot work at all. Inside the cells, most enzymes will work best in neutral conditions (pH 7). The pH or temperature at which an enzyme works best is called its optimum pH or temperature. Conditions in the **duodenum** are slightly alkaline: the optimum pH for pancreatic **lipase** is pH 8.

Although changes in pH affect the activity of enzymes, these effects are usually reversible, i.e. an enzyme that is disabled by a low pH will restart its normal activity when its optimum pH is met again.



▲ **Figure 5.5** The effect of pH on digestive enzymes

Going further

Intracellular and extracellular enzymes

All enzymes are made inside cells. Most of them remain inside the cell to speed up reactions in the cytoplasm and nucleus. These are called **intracellular enzymes** ('intra' means 'inside'). Some enzymes made in the cells are let out of the cell to do their work outside. These are **extracellular enzymes** ('extra' means 'outside'). Fungi and bacteria (see 'Features of organisms' in Chapter 2) release extracellular enzymes to digest their food. A mould growing on a piece of bread releases starch-digesting enzymes into the bread and absorbs the soluble sugars that the enzyme produces from the bread. In the digestive systems of animals ('Human digestive system' in Chapter 8), extracellular enzymes are released into the stomach and intestines to digest the food.

Test yourself

1 Copy and complete the table using a tick (✔) or a cross (**x**) to show which of the following statements apply to enzymes and/or any other catalysts.

statement	enzymes	any other catalysts
Their activity is stopped by high temperature.		
They speed up chemical reactions.		
They are proteins.		
They are not used up during the reaction.		

2 How would you expect the rate of an enzyme-controlled reaction to change if the temperature was raised
   a from 20 °C to 30 °C
   b from 35 °C to 55 °C?
   Explain your answers.

3 Apple cells contain an enzyme that turns the tissues brown when an apple is peeled and left for a time. An apple dipped in boiling water does not go brown (Figure 5.6). Explain why this apple behaves differently.

▲ **Figure 5.6** Experiment to investigate enzyme activity in an apple. Slice A has been freshly cut. B and C were cut 2 days earlier, but C was dipped immediately in boiling water for 1 minute

4 Suggest why amylase from the mouth does not work in the stomach.

5 Would **pepsin** from the stomach work effectively in the small intestine? Explain your answer.

6 With reference to enzymes, explain the meaning of the terms
   - complementary
   - active site.

7 Explain why, in an enzyme-controlled reaction in the human body, the rate of reaction starts to go down at temperatures above 40 °C, even though there is more kinetic energy available for the molecules.

Practical work

Tests for proteins are described in Chapter 4. Experiments on the digestive enzymes amylase and pepsin are described in Chapter 8.

Safety

- Eye protection must be worn.
- Take care handling hydrogen peroxide – it can burn the skin
- Take care handling hot water or a water-bath.

1 Extracting and testing an enzyme from living cells

In this experiment, catalase is the enzyme to be extracted and tested and the substrate is hydrogen peroxide (H_2O_2). Some reactions in the cell produce hydrogen peroxide, which is poisonous. Catalase makes the hydrogen peroxide harmless by breaking it down to water and oxygen.

$$2H_2O_2 \xrightarrow{\text{catalase}} 2H_2O + O_2$$

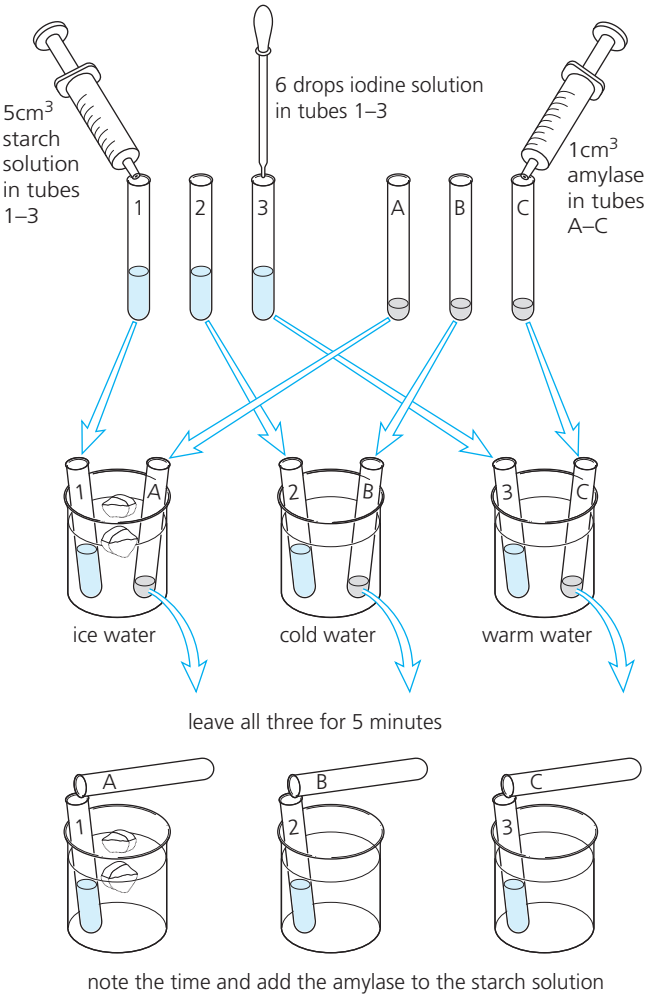
- Grind a small piece of liver with about 20 cm^3 water and a little sand in a mortar. This will break open the liver cells and release their contents.
- Filter the mixture and share it between two test tubes, A and B. The filtrate will contain many substances dissolved out from the cytoplasm of the liver cells, including enzymes. However, only one of these, catalase, will work on hydrogen peroxide because enzymes are specific.
- Add some drops of the filtrate from test tube A to a few cm^3 of 20 vol (6%) hydrogen peroxide in another test tube. You will see a strong reaction as the hydrogen peroxide breaks down to produce oxygen. (The oxygen can be tested with a glowing splint.)
- Now boil the filtrate in tube B for about 30 seconds. Add a few drops of the boiled filtrate to a fresh sample of hydrogen peroxide. There will be no reaction because boiling has denatured the catalase.
- Next, shake a little manganese(IV) oxide powder (***CARE:*** manganese(IV) oxide powder is harmful) in a test tube with some water and pour this into some hydrogen

peroxide. There will be a vigorous reaction like the one with the liver extract.
- Now boil some manganese(IV) oxide with water and add this to hydrogen peroxide. The reaction will still occur. Manganese(IV) oxide is a catalyst, but you know it is not an enzyme because heating has not changed its catalytic properties.
- The experiment can be repeated with a piece of potato to compare its catalase content with catalase in liver. Make the piece of potato about the same size as the liver sample.

Investigate a range of plant tissues to find out which is the best source of catalase. Decide how to make **quantitative** comparisons (observations which involve measurements). Possible plant tissues include cassava, potato, celery, apple and carrot.

2 The effect of temperature on an enzyme reaction

- Amylase is an enzyme that breaks down starch to a sugar (maltose).
- Use a plastic syringe (or graduated pipette) to measure 5 cm^3 of 5% amylase solution and place 1cm^3 in each of three test tubes labelled A, B and C.
- Rinse the syringe thoroughly and use it to place 5 cm^3 of a 1% starch solution in each of three test tubes labelled 1, 2 and 3.
- Using a dropping pipette, add six drops of dilute iodine solution to each of the tubes 1 to 3.
- Prepare three water-baths by half filling beakers or jars with
  - **a** ice and water. Keep adding ice during the experiment to keep the temperature at about 10 °C
  - **b** water from the cold tap at about 20 °C (if you are working in a hot room, add some ice as needed)
  - **c** warm water at about 35 °C by mixing hot and cold water.
- Place tubes 1 and A in the cold water-bath, tubes 2 and B in the water at 20 °C, and tubes 3 and C in the warm water.
- Leave the three beakers for 5 minutes to reach the temperature of the water they are each in (Figure 5.6).
- After 5 minutes, take the temperature of each water-bath, then pour the amylase from tube A into the starch solution in tube 1. Then put tube 1 back in the water-bath.
- Repeat this with tubes 2 and B, and 3 and C.
- As the amylase breaks down the starch, it will cause the blue colour to disappear. Make a note of how long this takes in each case.



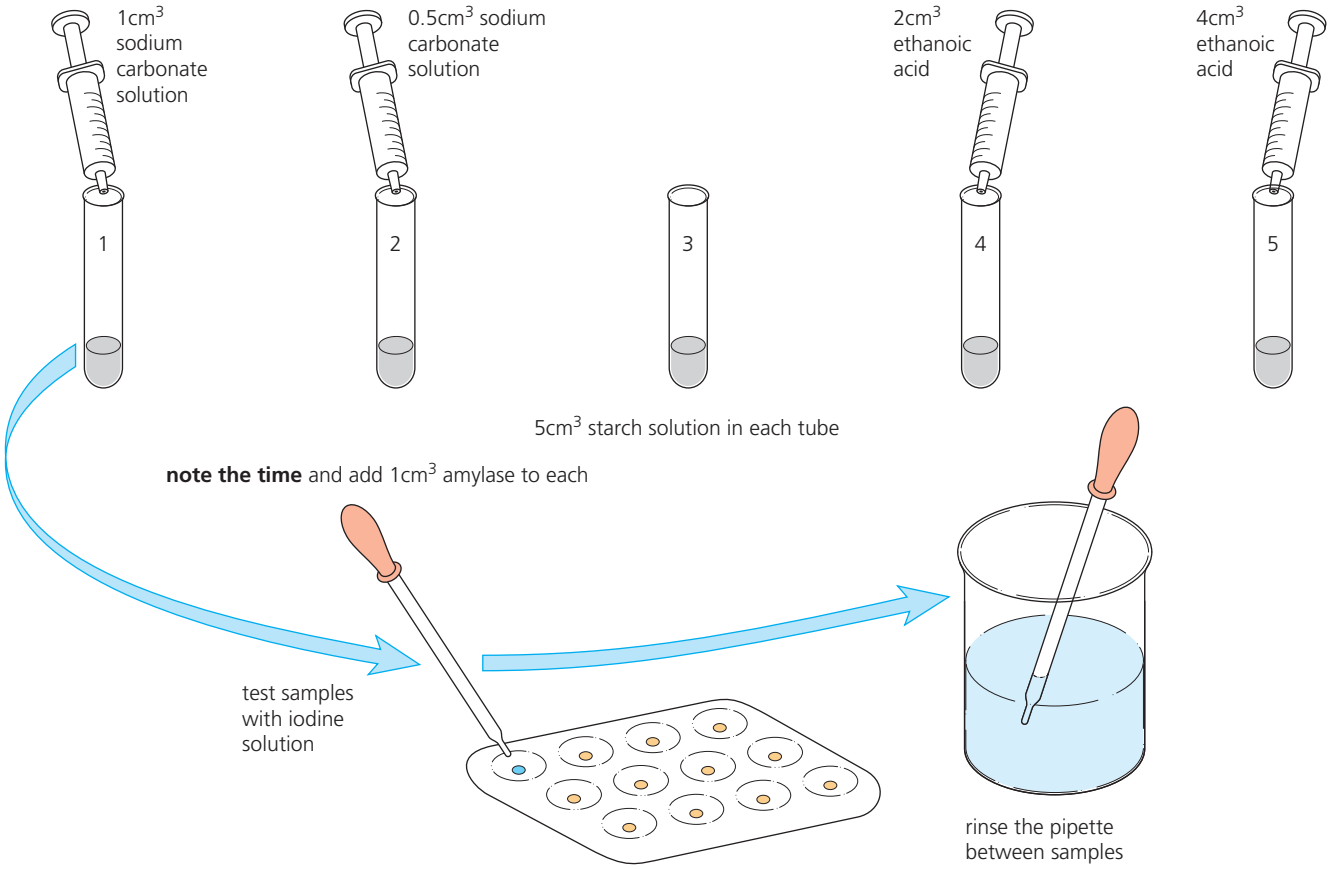
▲ **Figure 5.7** Experiment to investigate the effect of temperature on an enzyme reaction

3 The effect of pH on an enzyme reaction

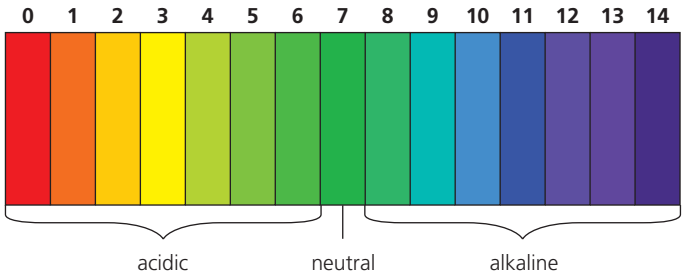
- Label five test tubes 1 to 5 and use a plastic syringe (or graduated pipette) to place 5 cm^3 of a 1% starch solution in each tube.
- Add acid or alkali to each tube as shown in the table. Rinse the syringe when changing from sodium carbonate to acid.

Tube	Chemical	Approximate pH	
1	1 cm^3 sodium carbonate solution (0.05 mol dm^{-3})	9	(alkaline)
2	0.5 cm^3 sodium carbonate solution (0.05 mol dm^{-3})	7–8	(slightly alkaline)
3	nothing	6–7	(neutral)
4	2 cm^3 ethanoic (acetic) acid (0.1 mol dm^{-3})	6	(slightly acid)
5	4 cm^3 ethanoic (acetic) acid (0.1 mol dm^{-3})	3	(acid)

- Place several rows of iodine solution drops in a cavity tile.
- Place 5 cm^3 of 5% amylase solution in a clean syringe and place 1 cm^3 in the first tube. Shake the tube and note the time (Figure 5.7).
- Using a clean dropping pipette, remove a small sample from the tube and add one drop to one of the iodine solution drops in the cavity tile. Rinse the pipette in a beaker of water between each sample. Keep on sampling in this way every 30 seconds.
- When any of the samples does not give a blue colour, this means that the starch in that tube has been completely broken down to sugar by the amylase. Note the time when this happens for the tube. Stop taking samples from that tube.
- Repeat with each of the remaining tubes.
- Stop sampling the remaining tubes after about 15 minutes. Put a drop from each tube on to a piece of pH paper or mix with a few drops of universal indicator solution in a cavity tile. Compare the colour produced with a colour chart of pH values.



▲ **Figure 5.8** Experiment to investigate the effect of pH on an enzyme reaction



▲ **Figure 5.9** A colour chart for Universal Indicator

Revision checklist

After studying Chapter 5 you should know and understand the following:

- ✔ Catalysts are substances that increase the rate of chemical reactions and are not changed by the reaction.
- ✔ Enzymes are proteins that function as biological catalysts.
- ✔ Enzymes are important in all organisms because they maintain a reaction speed needed to sustain life.
- ✔ The substance on which an enzyme works is called the substrate. After the reaction, a product is formed.
- ✔ Enzymes tend to be very specific in the reactions they catalyse due to the complementary shape of the enzyme and its substrate.
- ✔ When an enzyme catalyses a reaction, it forms a temporary enzyme–substrate complex before the product is released.
- ✔ Changes in temperature affect the kinetic energy of enzyme molecules and their shape.
- ✔ Enzymes can be denatured by changes in temperature and pH.
- ✔ Changes in pH affect the shape of enzyme molecules.

Exam-style questions

1 a i) Explain the term *enzyme*. [2]

ii) State **two** ways in which an inorganic catalyst is different from an enzyme. [2]

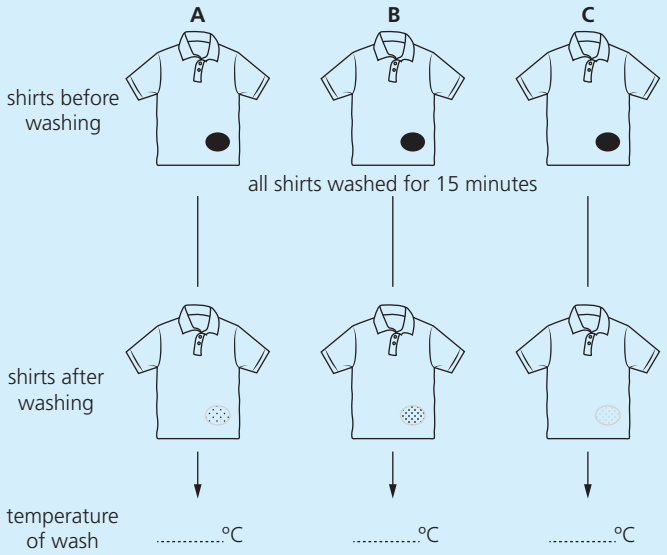
b Explain how the speed of an enzyme-controlled reaction is affected by changes in

i) temperature [3]

ii) pH. [3]

Support your answers using sketch graphs.

2 The diagram shows an experiment to investigate the effect of temperature on removing fat stains using an enzyme-containing washing powder. Three identical T shirts with identical fat stains were washed with the washing powder at three different temperatures, 15 °C, 35 °C and 70 °C.



a Complete the diagram to state the temperature at which each shirt was washed. [1]

b Explain the result for shirts A, B and C. [1]

c Suggest two changes to the method which could have resulted in the complete removal of the stain from shirt C. [2]

d i) State the name of the type of enzyme that was present in the washing powder. [1]

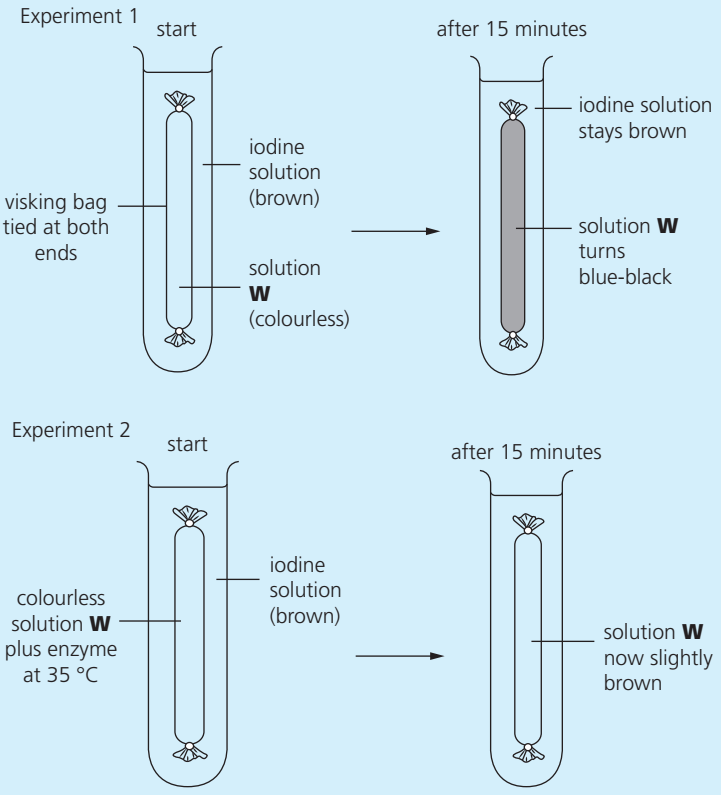
ii) Another shirt had blood stains. Suggest an enzyme that would need to be present in the washing powder to remove these stains. [1]

3 a i) Describe how you would carry out an investigation to show the effect of changing temperature on the reaction between a piece of vegetable and hydrogen peroxide. [6]

ii) State **two** safety precautions you would take when carrying out this investigation. [2]

b Explain why digestion of starch in bread, started in the mouth, stops when the bread reaches the stomach. [2]

4 The diagram shows an investigation into the permeability of Visking tubing and the action of an enzyme on an unknown solution.



a i) State what the results of experiment 1 indicate about the permeability of the Visking bag to iodine solution. [1]

ii) Suggest what nutrient was present in the solution. [1]

iii) Suggest why the iodine solution surrounding the bag stayed brown. [1]

b In experiment 2:

i) Suggest why the enzyme in the bag was kept at 35 °C. [1]

ii) Explain why the solution in the bag was still brown after 15 minutes. [2]

5 Two groups of students carried out an investigation into the effect of temperature on the reaction between hydrogen peroxide and the enzyme catalase in sweet potato extract. The reaction produces oxygen, which was collected for 10 minutes at each temperature.
The results are shown in the table below.

temperature/°C	volume of oxygen produced/cm^3	
	group 1	group 2
20	9	7
30	38	36
40	52	50
50	35	33
60	10	8

a Calculate the mean volume of oxygen produced at each temperature. [2]

b Plot a graph of the mean results. Label the axes. [4]

c **i)** Suggest the optimum temperature for the reaction. [1]

ii) Predict what the volume of oxygen produced would be at 70 °C. [1]

iii) The students expected that the enzyme would be denatured at temperatures above body temperature. Explain why the volume of oxygen produced at 50 °C was not zero. [2]

d For the reaction in the investigation, state the name(s) of

i) the substrate [1]

ii) the products. [2]

6 Plant nutrition

Focus

In the previous two chapters you found out about biological molecules, the properties of enzymes and their role in cells. Now we can apply that knowledge to a group of living organisms: photosynthesising plants. They are adapted to make their own biological molecules through the process of photosynthesis. Every step in the process is controlled by enzymes. At the end of this chapter you will be able to answer these questions: What food do plants make? What do they use it for? How do they make use of the properties of different biological molecules?

Photosynthesis

FOCUS POINTS

- ★ What is photosynthesis?
- ★ What is chlorophyll and what does it do?
- ★ How are the products of photosynthesis stored and what are they used for?
- ★ What is the effect of light intensity, carbon dioxide concentration and temperature on the rate of photosynthesis?

Key definitions

Photosynthesis is the process by which plants make carbohydrates from raw materials using energy from light.

All living organisms need food. They need it as a source of raw materials to build new cells and tissues as they grow. They also need food as a source of energy. Food is a kind of fuel that drives vital living processes and enables chemical changes (see 'Diet' in Chapter 8 and 'Aerobic respiration' in Chapter 10). Animals take in food, digest it and use the digested products to build their tissues or to release energy.

Plants also need energy and raw materials but, apart from a few insect-eating species, plants do not take in food. The most likely source of their raw materials seems to be the soil. However, experiments show that the weight gained by a growing plant is much more than the weight lost by the soil it is growing in. So there must be other sources of raw materials.

A hypothesis or theory to explain the source of food in a plant is that it *makes it* from air, water and soil mineral salts. Carbohydrates (like glucose, $C_6H_{12}O_6$ – see Chapter 4) contain the elements carbon, hydrogen and oxygen. The carbon and oxygen could be supplied by carbon dioxide (CO_2) from the air, and the hydrogen could come from the water (H_2O) in the soil. The nitrogen and sulfur needed for making proteins (Chapter 4) could come from nitrates and sulfates in the soil.

When complicated food molecules are built up from simpler substances the process is called **synthesis**. It needs enzymes and energy to make it happen. The enzymes are present in the plant's cells. The energy for the first stages in the synthesis comes from sunlight. So, the process is called photosynthesis ('photo' means 'light'). There is evidence that the green substance, chlorophyll, in the chloroplasts of plant cells is involved in photosynthesis. Chlorophyll absorbs sunlight and provides the energy it gains for chemical reactions. So, the function of chlorophyll is to convert light energy to chemical energy to form glucose and other carbohydrates.

The chemical equation for photosynthesis is

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

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

Make sure you remember the number of each type of molecule as well as the symbols.

In order to keep the equation simple, glucose is shown as the food compound produced. However, the glucose is quickly converted to sucrose for transportation around the plant. Then it is stored as starch or converted into other molecules.

The process of photosynthesis

The details of photosynthesis are not the same in all plants. However, the hypothesis given in this chapter has been supported by a lot of experimental testing and is accepted around the world. The next section describes how photosynthesis takes place in a plant.

The process takes place mainly in the cells of the leaves (Figure 6.1) and is summarised in Figure 6.2. In land plants, water is absorbed from the soil by the roots. It is carried in the water vessels of the veins, xylem, up the stem to the leaf. Carbon dioxide is absorbed from the air through the stomata (pores in the leaf, see 'Leaf structure' later in this chapter). In the leaf cells, the carbon dioxide and water are joined to make glucose; the energy for this reaction comes from sunlight, which has been absorbed by the green pigment chlorophyll in the chloroplasts of the leaf cells. The reaction takes place here. Chloroplasts (Figure 6.2(d)) are small, green structures present in the cytoplasm of the leaf cells. Chlorophyll is the substance which makes leaves and stems look green. It absorbs energy from light and uses it to split water molecules into hydrogen and oxygen. The oxygen escapes from the leaf and the hydrogen molecules join with carbon dioxide molecules to make glucose. In this way the energy from light has been transferred into energy in chemicals (carbohydrates) as they are made.

▲ **Figure 6.1** All the reactions involved in producing food take place in the leaves. You can see that the leaves do not overlap a lot to make sure they absorb as much light as possible

The plant's use of photosynthetic products

Glucose

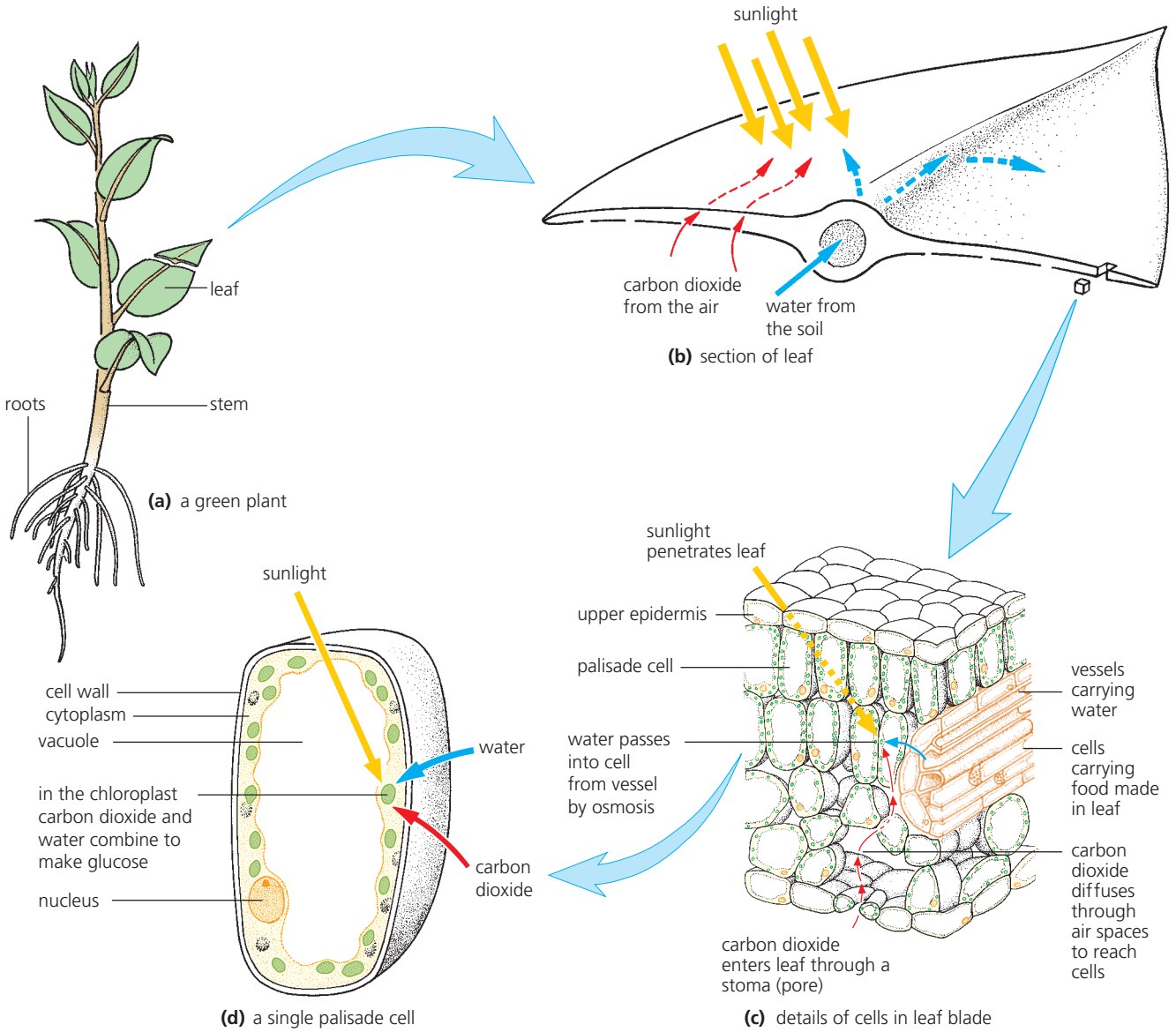
The glucose produced during the process of photosynthesis is used in respiration to provide energy. It is quickly changed to sucrose for transport around the plant.

Starch

Glucose that is not needed for respiration is turned into starch and stored or changed into other molecules.

Starch molecules are added to the growing starch granules in the chloroplast. If the glucose concentration increased in the mesophyll cells of the leaf, it could affect the osmotic balance between the cells (see 'Osmosis' in Chapter 3). Starch is a relatively insoluble compound, so it does not alter the concentration of the cell contents.

Some plants store it as starch grains in the cells of their stems or roots. Other plants, like the potato or cassava, have special storage organs (tubers) for holding the reserves of starch (see 'Asexual reproduction' in Chapter 16). Sugar is stored in the fruits of some plants. For example, grapes contain up to 25% glucose and other sugars.



▲ **Figure 6.2** Photosynthesis in a leaf

Sucrose

The starch is steadily broken down to sucrose (Chapter 4), which is soluble. The sucrose is transported out of the cell into the phloem. These are the food-carrying cells (see Chapter 7) of the leaf veins. These veins will pass the sucrose to all parts of the plant that do not photosynthesise, for example, the growing buds, the ripening fruits, the roots and the underground storage organs.

The cells in these places will use the sucrose in many ways (Figure 6.3).

Cellulose

Plant cell walls are made of cellulose. Cellulose molecules are long chains of glucose (see Figure 4.4 in Chapter 4). They make a tough meshwork round the outside of the cell – the cell wall (Figure 4.5). The cellulose cell wall holds in the contents of the cell but is freely **permeable** (it will allow most molecules to pass through).

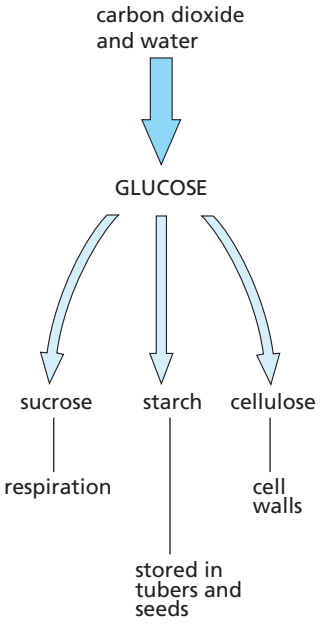
Respiration

The glucose can be used to provide energy. The process of respiration (Chapter 10) oxidises the glucose. The products are carbon dioxide and water, and the energy released is used for other chemical reactions like the building-up of proteins (see 'Proteins' in Chapter 4).

Test yourself

1 **a** State what substances a plant must take in to carry out photosynthesis.
b Describe where the plant gets each of these substances from.
c State what must be present in the cells to make photosynthesis work.

2 Which of the following are needed to produce starch in a leaf?
carbon dioxide, oxygen, nitrates, water, chlorophyll, soil, light



▲ **Figure 6.3** Green plants can make all the materials they need from carbon dioxide, water and salts

Practical work

Safety

- Eye protection must be worn.

Experiments to investigate photosynthesis

Controlled experiments

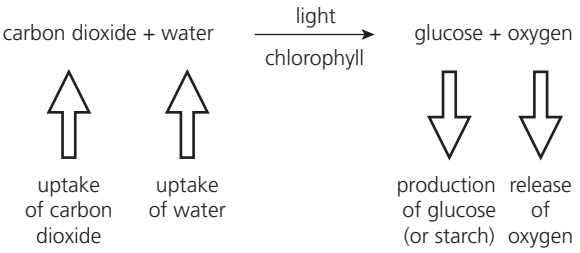
In most biological experiments, a second experiment called a control is set up. This is to make sure that the results of the first experiment are due to the conditions being studied and not to some other cause that has been missed.

The term '*controlled experiment*' refers to the fact that the experimenter (1) sets up a control and (2) controls the conditions in the experiment.

If you did an experiment to compare the **growth** of plants in the house and in a glasshouse, you could not be sure whether it was the extra light or the high temperature of the glasshouse that caused better growth. So, this would not be a properly controlled experiment. You must alter only one condition (called a variable) at a time, either the light or the temperature, and then you can compare the results with the control experiment.

So, a properly controlled experiment alters only one variable at a time and includes a control, which shows that it is this condition and nothing else that gave the result.

A hypothesis is an attempt to explain a group of observations. Here, the hypothesis is that plants make their food by photosynthesis. You were introduced to the equation for photosynthesis near the start of the chapter. It is one way of stating the hypothesis and is used here to show how it might be tested.



If photosynthesis is happening in a plant, then the leaves should be producing glucose. In many leaves, as fast as glucose is produced, it is turned into starch. It is easier to test for starch than for glucose, so we accept the presence of starch in a leaf to show that photosynthesis has taken place.

The first three experiments described below are designed to see if the leaf can make starch without chlorophyll, sunlight or carbon dioxide. If the photosynthesis hypothesis is correct, then if any one of these three conditions is missing, photosynthesis should stop. This will stop the production of starch. However, if the plant keeps making starch, then the hypothesis does not work, and it must be changed.

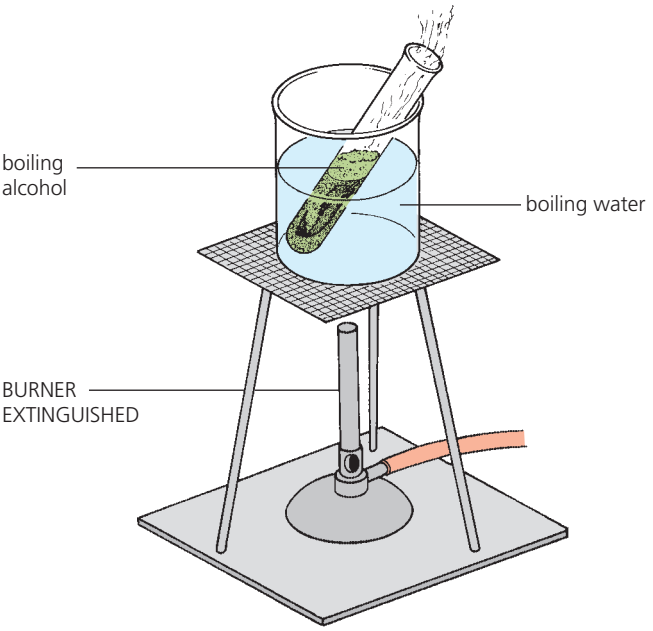
In designing the experiments, it is very important to make sure that only *one* variable is changed. If, for example, the method of keeping light from a leaf also stops its carbon dioxide supply, you could not decide if it was the lack of light or lack of carbon dioxide which stopped starch being made. To make sure that the experimental design has not changed more than one variable, a control is set up in each case. This is an identical situation, except that the condition missing from the experiment, for example, light, carbon dioxide or chlorophyll, is present in the control (see 'Aerobic respiration' in Chapter 10).

Destarching a plant

If the presence of starch is your evidence that photosynthesis is taking place, then you must make sure that there is no starch in the leaf at the beginning of the experiment. We do this by destarching the leaves. It is not possible to remove the starch chemically without damaging the leaves, so a plant is destarched by leaving it in darkness for 2 or 3 days. In the darkness, any starch in the leaves will be changed to sugar and carried away to other parts of the plant. For plants growing outside, the experiment is set up on the day before the test. During the night, most of the starch will be removed from the leaves. Another way is to cover some leaves in aluminium foil or black card for 2 days while they are still growing on the plant. Then you can test one of these leaves to see that no starch is present.

Testing a leaf for starch

When you mix iodine solution (yellow/brown) and starch (white) they make a deep blue colour. So, the test for starch is to add iodine solution to a leaf to see if it goes blue. However, iodine solution cannot soak into the leaf and the chlorophyll in the leaf hides any colour change. So, the leaf is treated as described below:



▲ **Figure 6.4** Experiment to remove chlorophyll from a leaf

- Heat some water to boiling point in a beaker and then ***turn off the Bunsen flame***.
- Use forceps to dip a leaf in the hot water for about 30 seconds. This kills the cytoplasm, denatures the enzymes and makes the leaf more permeable to iodine solution.
- **Note: make sure the Bunsen flame is turned off before starting the next part of the procedure. Remember that ethanol is flammable.**

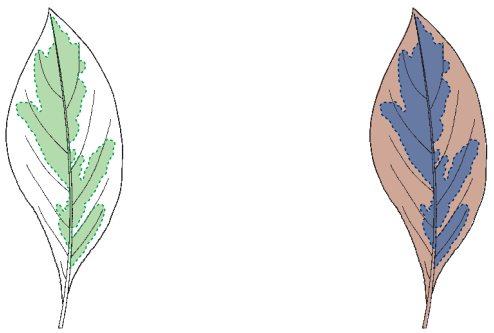
- Push the leaf to the bottom of a test tube and cover it with ethanol (alcohol). Chlorophyll dissolves in ethanol. Place the tube in the hot water (Figure 6.4). The alcohol has a boiling point of 78 °C, so it will boil and most of the chlorophyll will be removed from the leaf. When the iodine solution changes colour, the colour change is easier to see.
- Pour the green alcohol into another beaker, remove the leaf and dip it into the hot water again. This softens the leaf so you can spread it out.
- Spread out the decolourised leaf on a white tile and drop iodine solution on to it. The parts containing starch will turn blue with iodine solution; parts without starch will stain brown or yellow.

1 Is chlorophyll necessary for photosynthesis?

It is not possible to remove chlorophyll from a leaf without killing it, and so a variegated leaf, (a leaf with only patches of chlorophyll) is used. A leaf like this is shown in Figure 6.5(a). The white part of the leaf works as the experiment, because it has no chlorophyll in it. The green part with chlorophyll is the control. After being destarched, the leaf – still on the plant – is exposed to daylight for a few hours. Remove a leaf from the plant and draw it carefully to show where the chlorophyll is (i.e. the green parts). Then you can test it for starch as described above.

Result

Only the parts that had chlorophyll in them turn blue with iodine solution. The parts that were white stain brown (Figure 6.5(b)).



(a) variegated leaf **(b)** after testing for starch

▲ **Figure 6.5** Experiment to show that chlorophyll is necessary

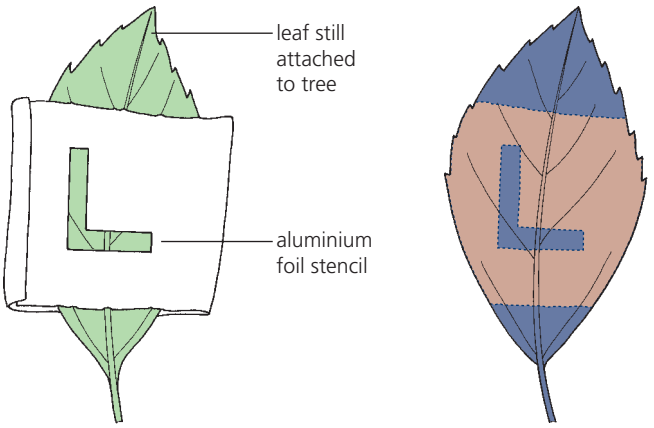
Interpretation

Starch is only present in the parts that contained chlorophyll, so this suggests that chlorophyll is needed for photosynthesis.

However, there are other possible explanations which this experiment has not ruled out. For example, starch could be made in the green parts and glucose in the white parts. Other explanations like this could be tested by further experiments.

2 Is light necessary for photosynthesis?

- Cut a simple shape from a piece of aluminium foil (or black card) to make a stencil and fix it to a destarched leaf (Figure 6.6(a)).
- After 4 to 6 hours of daylight, remove the leaf and test it for starch.



(a) at the start **(b)** after testing for starch

▲ **Figure 6.6** Experiment to show that light is necessary

Result

Only the areas that had received light go blue with iodine solution (Figure 6.6(b)).

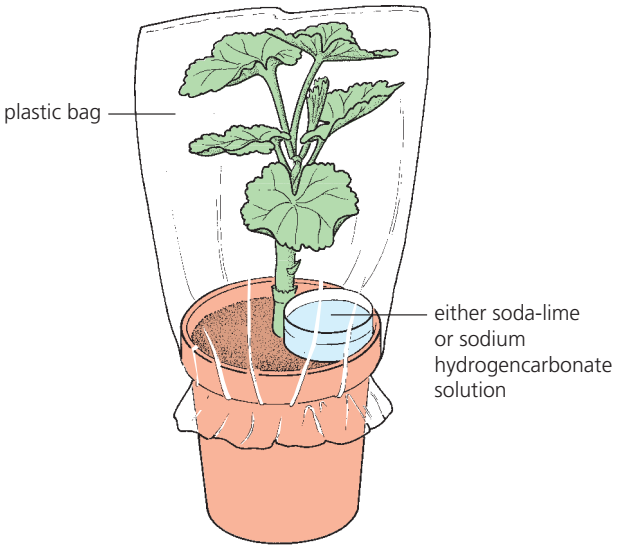
Interpretation

Starch has not formed in the areas that received no light, so light is needed for starch formation, and therefore light is needed for photosynthesis.

It is possible that the aluminium foil had stopped carbon dioxide from entering the leaf, and so it was a shortage of carbon dioxide rather than a shortage of light that stopped photosynthesis happening. Another control could be designed, using transparent material instead of aluminium foil for the stencil.

3 Is carbon dioxide needed for photosynthesis?

- Water two destarched plants growing in pots and cover their shoots in polythene bags.
- Place a dish of soda lime in one pot to absorb the carbon dioxide from the air (the experiment). Place a dish of sodium hydrogencarbonate solution in the other pot to produce carbon dioxide (the control), as shown in Figure 6.7.
- Place both plants in the light for several hours and then test a leaf from each for starch.



▲ **Figure 6.7** Experiment to show that carbon dioxide is necessary

Result

The leaf that had no carbon dioxide does not turn blue. The one with carbon dioxide does turn blue.

Interpretation

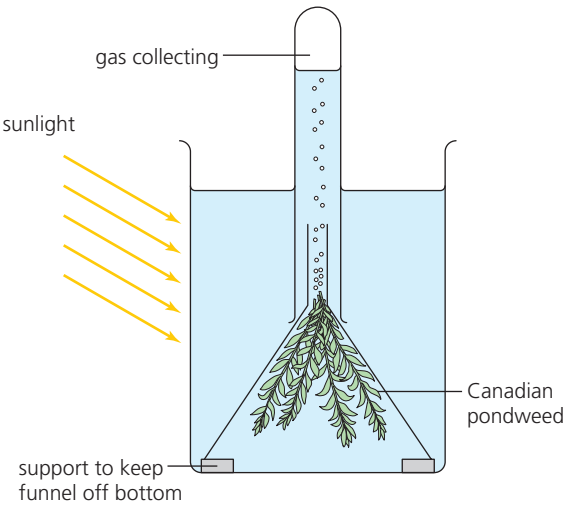
Starch was made in the leaves that had carbon dioxide, but not in the leaves that had no carbon dioxide. This suggests that this gas must be needed for photosynthesis. The control rules out the chance that high humidity or high temperature in the plastic bag stops normal photosynthesis.

4 Is oxygen produced during photosynthesis?

- Place a short-stemmed funnel over some Canadian pondweed in a beaker of water.
- Fill a test tube with water and place it upside-down over the funnel stem (Figure 6.8). (Raise the funnel above the bottom of the beaker to allow the water to circulate.)
- Place the apparatus in sunlight. Bubbles of gas should appear from the cut stems. The bubbles will rise and collect in the test tube.
- Set up a control in the same way, but place it in a dark cupboard.
- When enough gas has been collected from the plant in the light, remove the test tube and put a glowing splint in it.

Result

The glowing splint bursts into flames.



▲ **Figure 6.8** Experiment to show that oxygen is produced

Interpretation

The relighting of a glowing splint does not prove that the gas collected in the test tube is *pure* oxygen. However, it does show that it contains extra oxygen and this must have come from the plant. The oxygen is only given off in the light.

Note: Water contains dissolved oxygen, carbon dioxide and nitrogen. These gases could diffuse in or out of the bubbles as they pass through the water and collect in the test tube. So, the composition of the gas in the test tube may not be the same as the composition of the bubbles leaving the plant.

Practical work questions

1 In experiment 1 (the need for chlorophyll), explain why a separate control experiment was not needed.

2 **a** Explain what is meant by destarching a leaf.
b Explain why leaves need to be destarched before setting up some of the photosynthesis experiments.

3 In experiment 2 (the need for light),
a why was aluminium foil used for making the stencil?
b explain why the iodine solution stayed brown in the areas of leaf covered by the stencil.

4 In experiment 3 (the need for carbon dioxide), state the functions of
a the soda lime
b the sodium hydrogencarbonate
c the polythene bag.

5 **a** Suggest why a pondweed, rather than a land plant, is used for experiment 4 (the production of oxygen).
b Suggest why the use of a pond plant can make the results less useful.

Hypotheses

When setting up an experiment and a control, which of the two procedures is the control depends on how the prediction is worded. For example, if the prediction is that 'in the absence of light, the pondweed will not produce oxygen', then the control is the plant in the light. If the prediction is that 'the pondweed in the light will produce oxygen', then the control is the plant in darkness. As far as the results and interpretation are concerned, it does not matter which is the control and which is the experiment.

The hypothesis of photosynthesis was given at the beginning of this chapter and shown by the equation. The results of the four experiments support the hypothesis. Starch formation (our evidence for photosynthesis) only takes place in the presence of light, chlorophyll and carbon dioxide. Oxygen production only happens in the light.

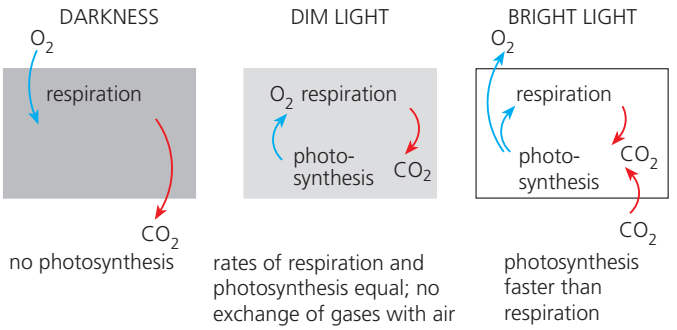
If starch or oxygen production had happened when any one of these conditions was missing, we would have to change our hypothesis about the way plants get their food. However, although our results support the photosynthesis theory, they do not prove it. For example, scientists have found that many stages in the production of glucose and starch from carbon dioxide do not need light.

Gaseous exchange in plants

Air contains the gases nitrogen, oxygen, carbon dioxide and water vapour. Plants and animals take in or give out these last three gases and this process is called gas exchange.

You can see from the equation for photosynthesis that one of its products is oxygen. So, in daylight, when photosynthesis is happening in green plants, they will be taking in carbon dioxide and giving out oxygen. This exchange of gases is the opposite of what happens in respiration (Chapter 10), but remember that plants respire as well as animals. The energy they need for all their living processes – apart from photosynthesis – comes from respiration and this is going on all the time, using up oxygen and producing carbon dioxide.

During the daylight hours, plants are photosynthesising as well as respiring, so that all the carbon dioxide produced by respiration is used up by photosynthesis. At the same time, all the oxygen needed by respiration is supplied by photosynthesis. However, carbon dioxide will be taken in and the excess oxygen is given out when the rate of photosynthesis is faster than the rate of respiration (Figure 6.9).



▲ **Figure 6.9** Respiration and photosynthesis

Test yourself

3 A green plant makes glucose from carbon dioxide and water. Suggest why it is not suitable to run an experiment using a plant without water to see if that stops photosynthesis.

4 When a plant is in bright sunlight, state which gases are
   a passing out of the leaf through the stomata
   b entering the leaf through the stomata.

Effects of external factors on the rate of photosynthesis

The rate of the light reaction depends on the light intensity. Water molecules in the chloroplasts will split faster as the light becomes brighter. The dark reaction is affected by temperature. The rate that carbon dioxide combines with hydrogen to make carbohydrate increases as the temperature increases.

Limiting factors

A **limiting factor** is something present in the environment in such short supply that it limits life processes.

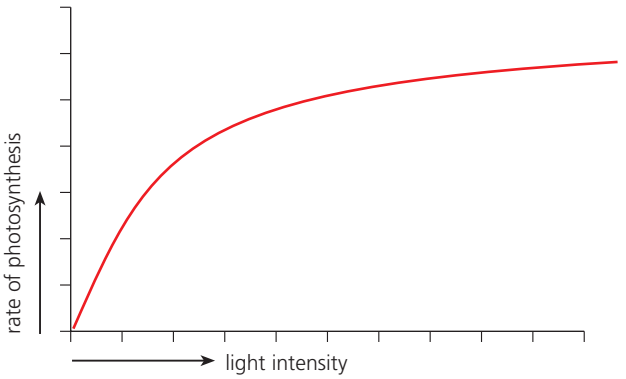
Studying Figure 6.10(a), you can see that an increase in light intensity does speed up photosynthesis, but only up to a point. Beyond that point, any further increase in light intensity has only a small effect. One explanation of this limit on the rate of increase is that all available chloroplasts are fully engaged in light absorption. So, even if the light intensity increases more, no more light can be absorbed and used. Alternatively, the limit could be because there is not enough carbon dioxide in the air to combine with the extra hydrogen atoms produced. Or, it may be that low temperature is limiting the rate of enzyme reactions.

Figure 6.10(b) shows that, if the temperature of a plant is raised, the effect of increased light intensity is not limited so much. So, in Figure 6.10(a), it is likely that the increase in the rate of photosynthesis could have been limited by the temperature. Any one of the external factors – temperature, light intensity or carbon dioxide concentration – can limit the effects of the other two. A temperature rise can cause photosynthesis to speed up, but only to the point where the light intensity limits further increase. In such conditions, the external factor that limits the effect of the others is called the limiting factor.

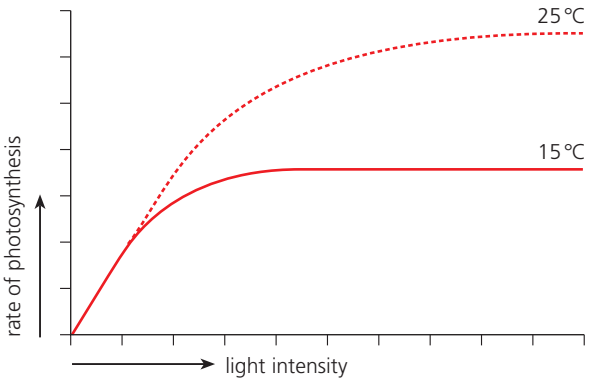
Artificially high levels of carbon dioxide in glasshouses do actually increase yields of crops (Figure 6.11).

Glasshouses and polytunnels also maintain a higher temperature and so reduce the effect of low temperature as a limiting factor, and they clearly optimise the light reaching the plants.

Parts of the world, for example, tropical countries, often benefit from optimum temperatures and rainfall for crop production. However, glasshouses and polytunnels are still often used because they allow the growers to control how much water and nutrients the plants receive, and they can also reduce crop damage by insect pests and disease. Sometimes rainfall is too great to benefit the plants. In an experiment in the Seychelles in the wet season of 1997, tomato crops in an open field yielded 2.9 kg m^{-2}. In a glasshouse, they yielded 6.5 kg m^{-2}.



(a) increasing light intensity



(b) increasing light intensity and temperature

▲ **Figure 6.10** Limiting factors in photosynthesis

In the natural environment, the factors most likely to limit the rate of photosynthesis are temperature and light intensity. Temperature affects the rate of enzyme-controlled reactions (see Chapter 5), while light provides the source of

energy for plants to synthesise organic molecules. In countries with a seasonal climate the winter months represent conditions of low temperature and low light intensity. These conditions make photosynthesis very slow. Plant species with an annual life cycle produce seeds that lie dormant until conditions are more favourable for growth (see the section on germination in Chapter 16). Other plants produce vegetative structures in the form of bulbs, corms (an underground storage system that looks like a bulb but is made up of a swollen stem rather than fleshy leaves), rootstocks or tubers (see Chapter 16). Only in spring when the light intensity and temperature start to rise do these structures start to grow, produce leaves and begin to photosynthesise. Grass in a lawn stops growing when the temperature drops to 5°C because photosynthesis is so slow.

Some woodland plants, such as bluebells, complete their growing season early in spring, before the trees above them have developed new leaves, so that they can benefit from the light when it is available.

Some ecosystems present plants with quite extreme conditions. For example, in the arctic tundra, for much of the year the temperature and light intensity are very low. In tropical forests, although plants in the canopy receive light of very high intensity, those at ground level are shaded. However, plants growing there benefit from consistently high mean temperatures.

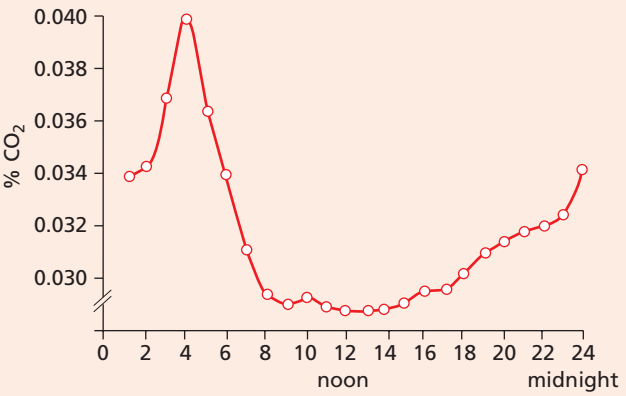
The idea of limiting factors applies to other processes as well as photosynthesis. For example, adding fertiliser to the soil can increase crop yields, so long as the roots can take up all the nutrients and the plant can build them into proteins, etc. The uptake of mineral ions is limited by several factors. These include the absorbing area of the roots, rates of respiration, aeration of the soil and availability of carbohydrates from photosynthesis.

▲ **Figure 6.11** Carrot plants grown in increasing concentrations of carbon dioxide from left to right

Test yourself

5 In a partially controlled environment like a glasshouse
   - **a** describe how you could change the external factors to obtain maximum photosynthesis
   - **b** suggest which of these alterations might not be cost effective.

6 Figure 6.12 is a graph showing the average daily change in the carbon dioxide concentration 1 metre above an agricultural crop during the summer. Using your knowledge of photosynthesis and respiration, explain the changes in the carbon dioxide concentration.



▲ **Figure 6.12** Daily changes in concentration of carbon dioxide 1 metre above a plant crop

Practical work

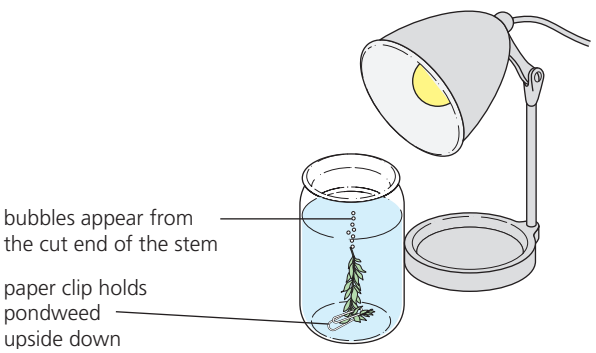
Safety

- Eye protection must be worn.
- Take care when using a scalpel, follow your teacher's guidance.
- Take care if using a mains electricity lamp – ensure your hands are dry when switching it on or off.

5 What is the effect of changing light intensity on the rate of photosynthesis? (Method 1)

In this investigation, we are going to use the rate of bubble production by a pond plant to calculate the rate of photosynthesis.

- Stir a spatula end of sodium hydrogen carbonate in a beaker of water or a boiling tube. This dissolves fast and saturates the water with carbon dioxide.
- Using a scalpel blade cut one end of the stem of a fresh piece of Canadian pondweed.
- Attach a piece of modelling clay or a paper clip to the stem and put it into the beaker (or boiling tube). This will help to stop the stem floating.
- Set up a light source 10 cm away from the beaker and switch on the lamp (Figure 6.13). Bubbles should start appearing from the cut end of the plant stem. Count the number of bubbles for a fixed time (e.g. 1 minute) and record the result. Repeat the count.

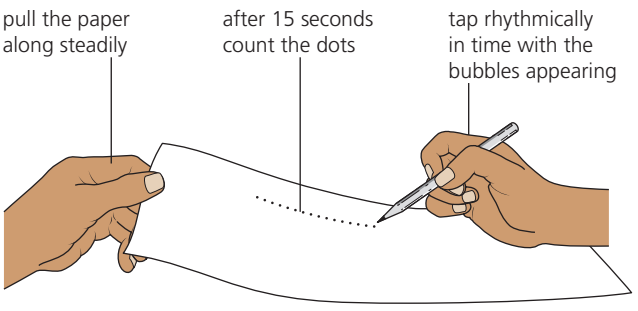


▲ **Figure 6.13** Experiment to investigate light intensity and oxygen production

- Now move the light source so that it is 20 cm from the beaker. Switch on the lamp and leave it for a few minutes. This will allow the plant to adjust to the new light intensity. Count the bubbles as before and record the results.
- Repeat the method so that the numbers of bubbles for at least five different distances have been recorded. Also, try switching off the bench lamp and see if there is any change in the number of bubbles.
- There is a relationship between the distance of the lamp from the plant and the light intensity received by the plant.

  $$\text{Light intensity} = \frac{1}{D^2} \text{ where D = distance}$$

- Use the equation to change the distances to light intensity. Use the data to plot a graph of light intensity/arbitrary units (*x*-axis) against rate of photosynthesis/bubbles per minute (*y*-axis).
  Note: In this investigation the heat given off from the bulb is another variable, which could affect the rate of photosynthesis. To improve the method, another beaker of water could be placed between the bulb and the plant. This filters the heat but allows the plant to receive the light.
- If the bubbles appear too fast to count, try tapping a pen or pencil on a sheet of paper at the same rate as the bubbles appear. Get your partner to slide the paper slowly along for 15 seconds. Then you can count the dots (Figure 6.14).



▲ **Figure 6.14** Estimating the rate of bubble production

Result

The rate of bubbling decreases as the lamp is moved further away from the plant. When the light is switched off, the bubbling stops.

Interpretation

If the bubbles contain oxygen produced by photosynthesis, then the rate of photosynthesis is

shown by the rate of oxygen bubble production. So, the rate of photosynthesis increases as the light intensity is increased. This is because the plant uses the light energy to photosynthesise. The oxygen is produced as a waste product.

The oxygen escapes from the plant through the cut stem. We need to assume that the size of the bubbles do not change during the experiment. A fast stream of small bubbles could be the same volume of gas as a slow stream of large bubbles.

Worked example

The table contains data from a student who carried out experiment 5.

distance from lamp/cm	number of bubbles in 1 minute for three sets of results			mean number of bubbles/min^{-1}
	1	2	3	
10	38	40	39	
20	15	17	26	
30	6	8	7	
40	3	3	3	
50	2	3	2	

As you can see in the table, the student collected three sets of data for each distance of the lamp from the pond plant. In order to plot a graph of the results, you need to calculate the mean number of bubbles for each distance.

This involves adding up the three values for each distance, then dividing the total by the number of sets of data (3).

So, for distance 10 cm, 38 + 40 + 39 = 117/3 = 39 bubbles per min

However, there is one result in the table which does not follow the normal pattern (an anomalous result). This should not be included in the means. Can you identify it?

The anomalous result is 26 (the third set of data, for 20 cm). When calculating the mean for this distance, only the values for set 1 and set 2 should be used (15 + 17) and the number of sets of data is 2 instead of 3.

So, the mean for a distance of 20 cm = 15 + 17 = 32 /2 = 16 bubbles per min

Once all the means have been calculated, the data can be used to make a graph.

The *x*-axis (horizontal) represents the independent (input) variable. This is the distance of the lamp from the plant. The *y*-axis (vertical) represents the dependent (output) variable. This is the mean number of bubbles. The results can be plotted as a line graph.

Tasks

1. Calculate the mean number of bubbles for each distance.
2. Plot a graph as described above. Label the axes and draw a line of best fit.
3. Describe the trend of the graph (what pattern it shows).
4. Write a conclusion.

Practical work

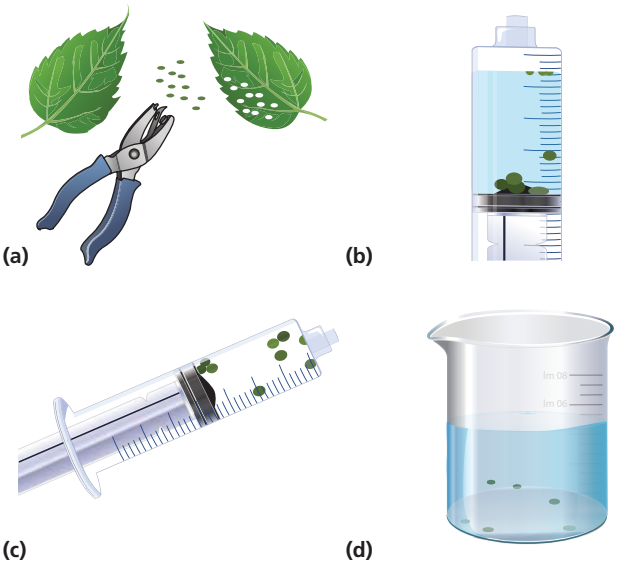
Safety

- Eye protection must be worn.
- Take care using a cork borer – place the leaves on a board, not on your hand.

6 What is the effect of changing light intensity on the rate of photosynthesis? (Method 2)

This investigation uses leaf discs from land plants.

- Use a cork borer or paper hole punch to cut out discs from a fresh, healthy leaf like spinach, avoiding any veins (Figure 6.15(a)). The leaves contain air spaces. These make the leaf discs float when they are placed in water.
- At the start of the experiment, the air needs to be removed from the discs. To do this put about 10 discs in a large (10 cm^3) syringe. Tap it so the discs sink to the bottom (opposite the plunger end).
- Place one finger over the hole at the end of the syringe barrel. Fill the barrel with water, then replace the plunger.
- Turn the syringe so the needle end is facing up and release your finger.
- Gently push the plunger into the barrel of the syringe. This will force out any air from above the water (Figure 6.15(b)).



▲ **Figure 6.15** Using leaf discs to investigate the effect of light intensity on photosynthesis

- Now replace your finger over the syringe hole and withdraw the plunger to create a vacuum.
- Keep the plunger withdrawn for about 10 seconds. This sucks out all the air from the leaf discs. They should then sink to the bottom (Figure 6.15(c)). Release the plunger.
- Repeat the method if the discs do not all sink.
- Dissolve a spatula of sodium hydrogencarbonate in a beaker of water. Remove the discs from the syringe and place them in the beaker (Figure 6.15(d)).
- Start a stopwatch and record the time taken for each of the discs to float to the surface. Ignore those that did not sink. Calculate an average time for the discs to float.
- Repeat the method, varying the light intensity the discs are exposed to in the beaker (see experiment 5 for varying the light intensity produced by a bench lamp).

Result

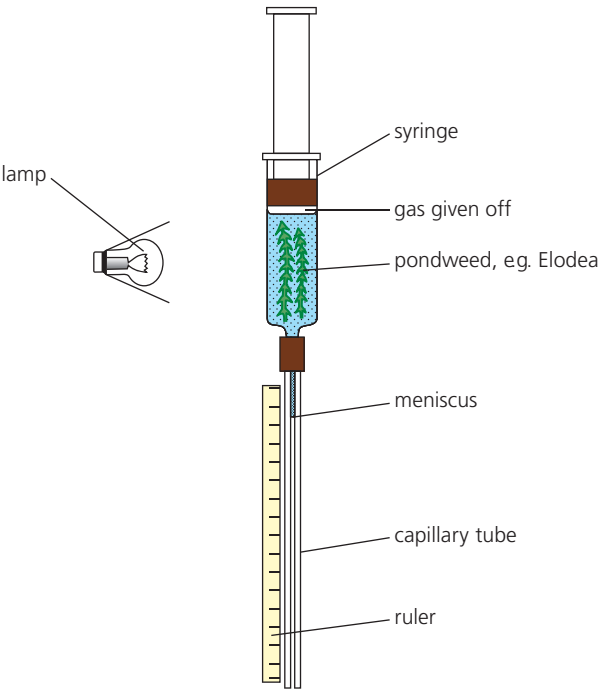
The greater the light intensity, the quicker the leaf discs float to the surface.

Interpretation

As the leaf discs photosynthesise, they produce oxygen. This is released into the air spaces in the disc. The oxygen makes the discs more buoyant, so as the oxygen builds up, they float to the surface of the water. As light intensity increases, the rate of photosynthesis increases.

7 What is the effect of changing carbon dioxide concentration on the rate of photosynthesis?

When sodium hydrogencarbonate is dissolved in water it releases carbon dioxide. Use the apparatus shown in Figure 6.16.



▲ **Figure 6.16** Apparatus for investigating the effect of changing carbon dioxide concentration on the rate of photosynthesis

- To set this up, remove the plunger from the 20 cm^3 syringe. Place two or three pieces of pondweed, with freshly cut stems facing upwards, into the syringe barrel. Hold a finger over the end of the capillary tube and fill the syringe with distilled water.
- Replace the plunger and turn the apparatus upside-down. Push the plunger to the 20 cm^3 mark, making sure that no air is trapped.
- Set up the apparatus as shown in Figure 6.16. Move the syringe barrel until the **meniscus** is near the top of the graduations on the ruler. The bulb should be a fixed distance from the syringe, for example, 10 cm. (The meniscus is where the edge of the water surface curves upwards to touch the edge of the syringe).

- Switch on the lamp. Measure the distance the meniscus moves over 3 minutes. Repeat this several times, then calculate an average.
- Repeat the procedure using the following concentrations of sodium hydrogencarbonate solution: 0.010, 0.0125, 0.0250, 0.0500 and 0.1000 mol dm^{-3}.
- Plot a graph of the concentration of sodium hydrogencarbonate solution (*x*-axis) against the mean distance travelled by the meniscus (*y*-axis).

Result

The higher the concentration of sodium hydrogencarbonate solution, the greater the distance moved by the meniscus.

Interpretation

As the concentration of available carbon dioxide is increased, the distance travelled by the meniscus also increases. The movement of the meniscus is caused by oxygen production by the pondweed, due to photosynthesis. So, an increase in carbon dioxide increases the rate of photosynthesis.

8 What is the effect of changing temperature on the rate of photosynthesis?

Use the methods described in experiments 5 or 6, but vary the temperature of the water instead of the light intensity.

Practical work questions

6 In experiment 5 (changing light intensity)
- **a** explain why sodium hydrogencarbonate was put in the water
- **b** what factor, which could have affected the results, was not controlled in this experiment?

7 In experiment 6 (changing light intensity – method 2) what made the leaf discs float to the surface of the water?

8 In experiment 7 (changing carbon dioxide concentration) state three factors that needed to be kept constant.

9 In experiment 8 (changing temperature) explain why the rate increased as the temperature was increased.

Leaf structure

FOCUS POINTS

- ★ How are the features of leaves adapted for photosynthesis?
- ★ What is the structure of a leaf?
- ★ How are the leaf structures adapted for photosynthesis?

The relationship between a leaf and the rest of the plant is described in Chapter 7.

A broad-leaved plant has a leaf structure like the one shown in Figure 6.17(a). Figure 6.17(b) shows a transverse section through the leaf. It is attached to the stem by a leaf stalk. When this goes into the leaf it is called a midrib. A network of veins branches from the midrib. The veins bring water and mineral ions to the leaf cells and carry away the food made by them.

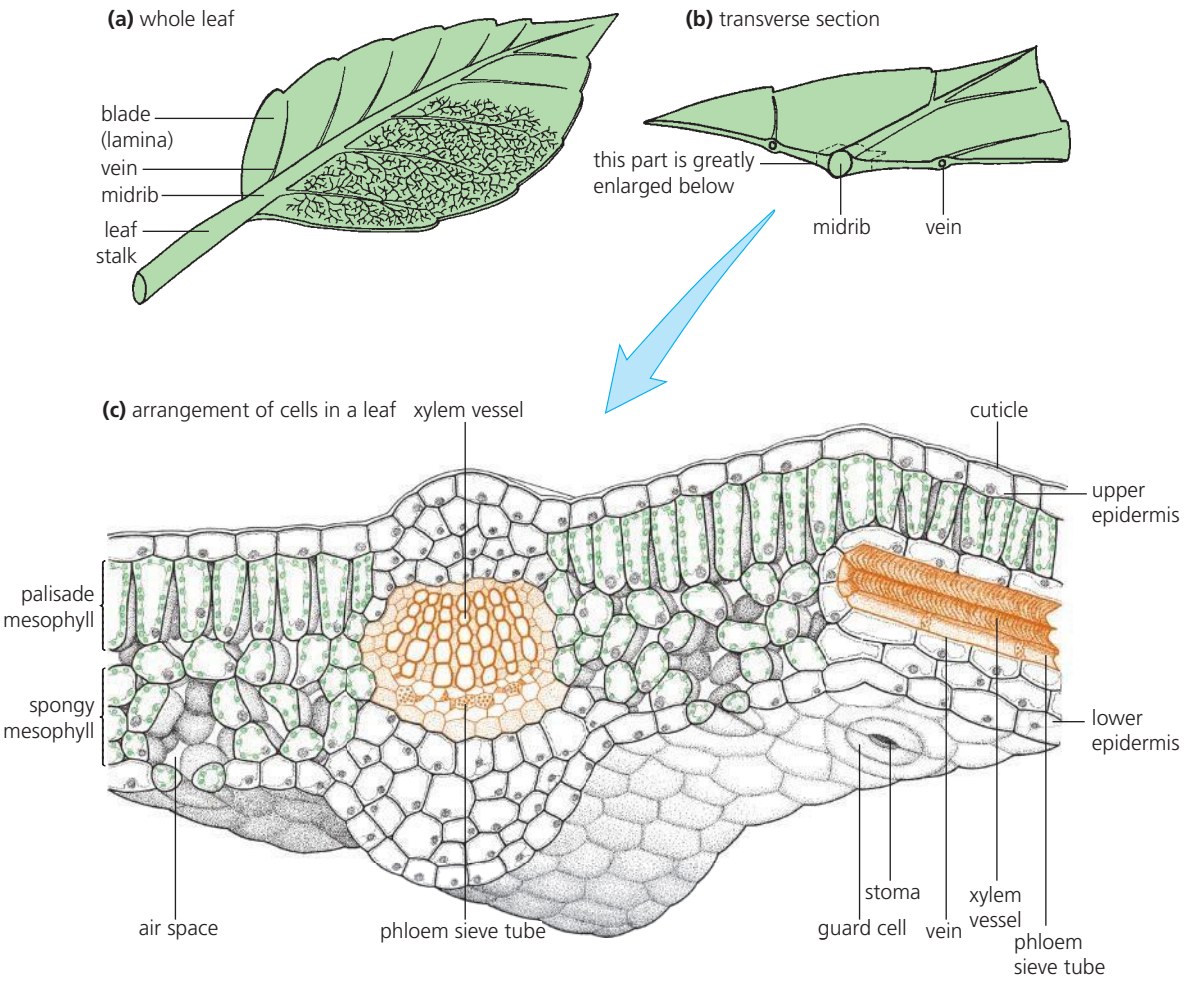
As well as carrying food and water, the network of veins makes a kind of skeleton that supports the softer tissues of the leaf blade.

The leaf blade (or lamina) is broad. A vertical section through a small part of a leaf blade is shown in Figure 6.17(c).

Adaptation of leaves for photosynthesis

When biologists say that something is adapted, they mean that its structure is well suited to its job. Although there are many types of leaf shape, the following statements apply to most leaves, and are shown in Figure 6.17(b) and (c).

- Their broad, flat shape gives a large surface area for the absorption of sunlight and carbon dioxide.
- Most leaves are thin, so the carbon dioxide only needs to diffuse across short distances to reach the inner cells.



▲ **Figure 6.17** Leaf structure

Parts of the leaf and their functions

Figure 6.18 is a photograph of a leaf section under the microscope.

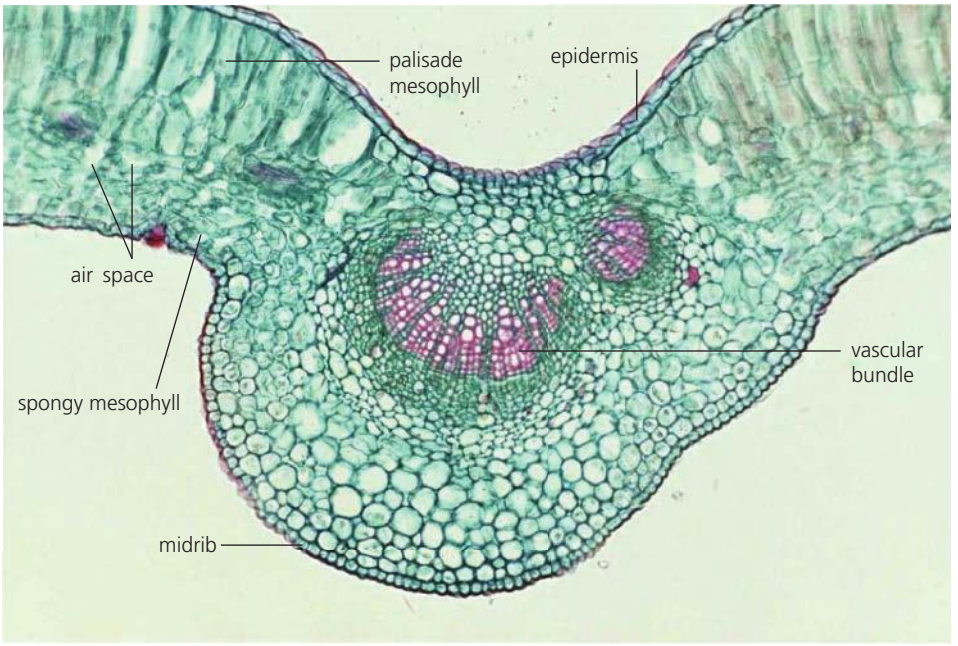
Epidermis

The epidermis is a single layer of cells on the upper and lower surfaces of the leaf. There is a thin waxy layer called the **cuticle** over the epidermis.

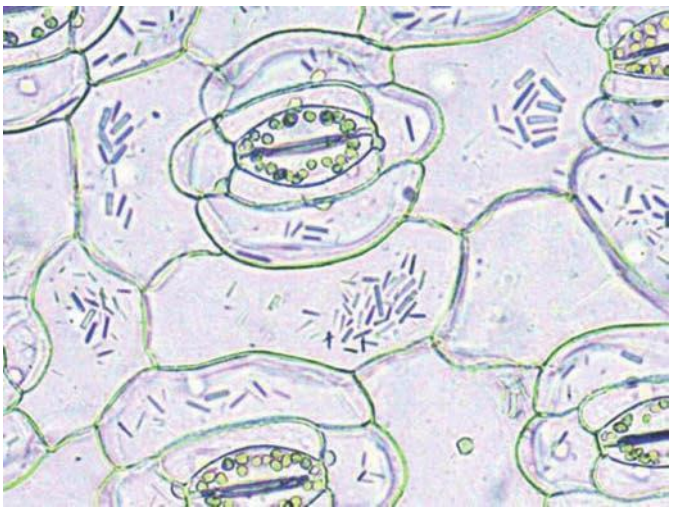
The epidermis helps to keep the leaf's shape. The closely fitting cells (Figure 6.17(c)) reduce evaporation from the leaf and prevent bacteria and fungi from getting in. The cuticle is a waxy layer lying over the epidermis that helps to reduce water loss. It is produced by the epidermal cells.

Stomata and guard cells

There are structures in the leaf epidermis called stomata (singular = **stoma**). A stoma consists of a pore enclosed by two **guard cells** (Figure 6.19). In most dicotyledons (i.e. the broad-leaved plants), the stomata are only present in the lower epidermis. However, the stomata in monocotyledons (i.e. narrow-leaved plants like grasses) are equally spread on both sides of the leaf.



▲ **Figure 6.18** Transverse section through a leaf (×30)



▲ **Figure 6.19** Stomata in the lower epidermis of a leaf (×350)

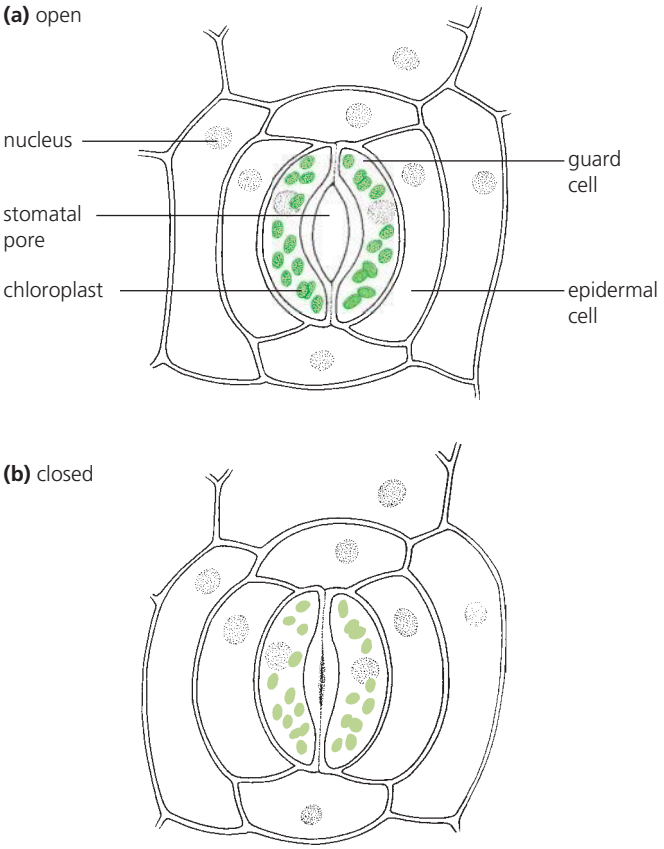
The shape of the guard cells change when the pressure of water in them changes (see 'Osmosis' in Chapter 3). When their shape changes, the stomatal pore can open or close. Usually, stomata are open in daylight but closed for most of the time when it is dark (Figure 6.20). However, the pattern of opening and closing depends on the plant species, allowing carbon dioxide and oxygen to be exchanged with the air outside. The leaf needs a source of carbon dioxide for photosynthesis.

If the stomata close, the carbon dioxide supply to the leaf cells is almost cut off and photosynthesis stops. However, the stomata are closed in many species during darkness, when photosynthesis is not taking place anyway.

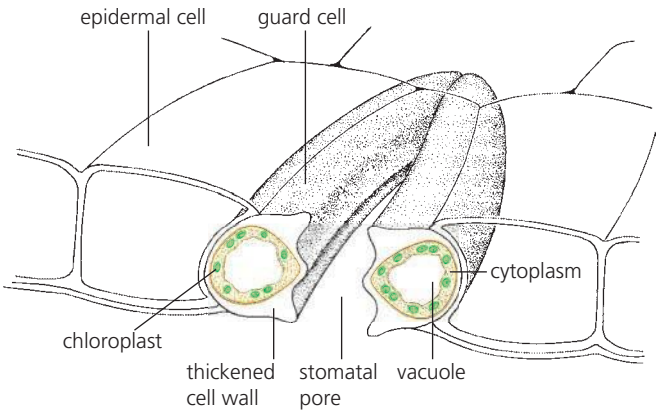
So, stomata allow carbon dioxide into the leaf when photosynthesis is taking place and prevent too much loss of water vapour (see 'Transpiration and translocation' in Chapter 7) when photosynthesis stops.

Scientists do not know exactly how the stomata open and close. However, they do know that in the light, the potassium concentration in the guard cell vacuoles increases. This makes the cell sap more concentrated (see 'Osmosis' in Chapter 3). So, water enters the guard cells by osmosis from the epidermal cells next to them. This flow of water into the cell increases the pressure of water inside the guard cells.

The cell wall next to the stomatal pore is thicker than other places in the cell and is more stiff (Figure 6.21). So, although the increased pressure of water makes the whole guard cell bigger, the thick inner wall cannot expand. This causes the guard cells to curve and the stomatal pore opens.



▲ **Figure 6.20** Stoma



▲ **Figure 6.21** Structure of guard cells

When potassium ions leave the guard cell, the concentration of the sap goes down and water passes out of the cells by osmosis. The pressure of water in the cell goes down and the guard cells straighten up, closing the stoma.

Scientists are still studying where the potassium ions come from and what makes them move into or out of the guard cells.

You can see from Figures 6.20 and 6.21 that the guard cells are the only epidermal cells containing chloroplasts. Scientists thought that the chloroplasts built up glucose by photosynthesis during daylight and that the glucose made the cell sap more concentrated. So, the pressure increased inside the cell. However, not much photosynthesis happens in these chloroplasts. We are not sure what their job is, though we do know that starch builds up in them during the night. In some species of plants, the guard cells have no chloroplasts.

Mesophyll

The tissue between the upper and lower epidermis is called mesophyll (Figure 6.17(c)). It is made of two areas: the upper, palisade mesophyll and the lower, spongy mesophyll (Figure 6.22). The palisade cells are usually long and contain many chloroplasts in the cytoplasm. Chloroplasts are green organelles, because they contain the pigment chlorophyll. The spongy mesophyll cells have different shapes and fit loosely together. This leaves many air spaces between them. They also contain chloroplasts.

The job of the palisade cells is to make food by photosynthesis. The spongy mesophyll cells also do this, but they contain less chloroplasts. Their chloroplasts absorb sunlight and use its energy to join carbon dioxide and water molecules. This makes glucose molecules, as described earlier in this chapter.

In daylight, when photosynthesis is fast, the mesophyll cells are using up carbon dioxide. So, the concentration of carbon dioxide in the air spaces goes down. More carbon dioxide diffuses in (Chapter 3) from the outside air, through the stomata (Figure 6.22). The carbon dioxide then diffuses through the air spaces, up to the cells which are using carbon dioxide. These cells are also producing oxygen, produced during photosynthesis. When the concentration of oxygen in the air spaces rises, it diffuses out through the stomata.

Air spaces

The large spaces between the spongy mesophyll cells inside the leaf make it easy for the carbon dioxide to diffuse. Water vapour goes into the air spaces, evaporated from the surface of the cells around them. This is part of the process of **transpiration** (see Figure 7.17 in Chapter 7).

Vascular bundles (veins)

The main vein of the leaf is called the midrib. Other veins branch off from this and make a network through the leaf. **Vascular bundles** are made of two

different types of tissues, called xylem and phloem. The xylem vessels are long, thin tubes with no cell contents when mature (cytoplasm, nucleus or sap vacuole). They have thickened cell walls, containing a material called **lignin**. This can make distinct patterns in the vessel walls, for example, spirals (see Chapter 7). Xylem carries water and salts to cells in the leaf. The phloem is made of sieve tubes. The ends of each long, thin cell have small holes in, making sieve plates. The cells are also different from xylem because they keep their contents.

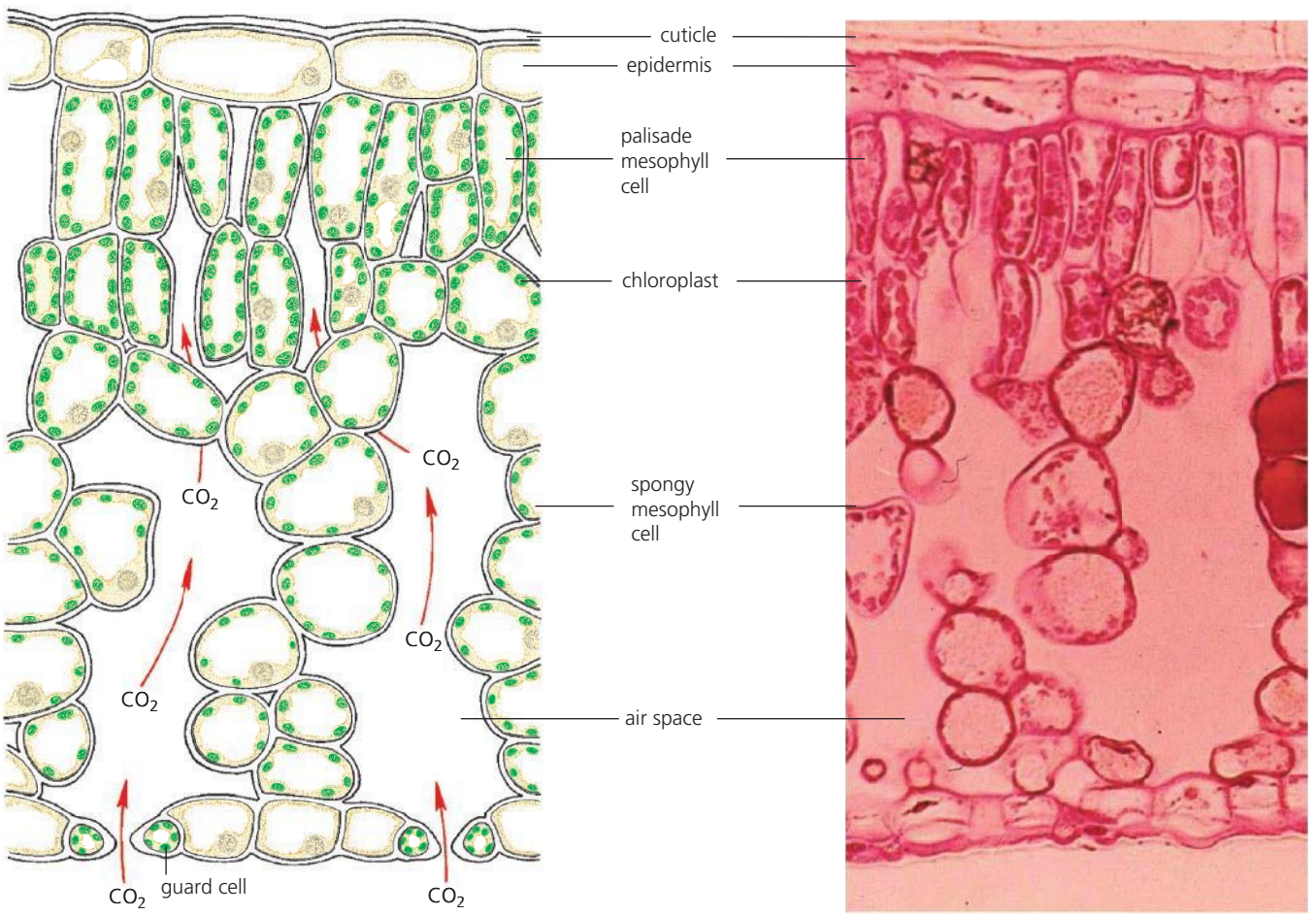
The water needed for making glucose by photosynthesis is transported to the mesophyll cells by the veins. The mesophyll cells take in the water by osmosis (Chapter 3) because the concentration of free water molecules in a leaf cell, which contains glucose, will be less than the concentration of water in the water vessels of a vein. The branching network of veins gives a good water supply to the photosynthesising cells. All the leaf cells are near a water-carrying vessel in one of these veins.

The sugars made in the mesophyll cells are passed to the phloem cells (Chapter 7) of the veins. Phloem cells carry the sugars and other food substances like amino acids away from the leaf and into the stem to other parts of the plant (a process called **translocation**).

Distribution of chloroplasts

There are more chloroplasts in the upper (palisade mesophyll) cells than in the lower (spongy mesophyll) cells. The palisade cells are near the upper surface, so they get most sunlight. This will reach the chloroplasts without being absorbed by many cell walls. There are also some chloroplasts in the guard cells (Figure 6.21). Other epidermal cells do not have chloroplasts.

Photosynthesis takes place mainly in the leaves, but any part of the plant that contains chlorophyll, for example, green stems, can photosynthesise.



▲ **Figure 6.22** Vertical section through a leaf blade (×300)

▼ **Table 6.1** Summary of parts of a leaf

Part of leaf	Details
cuticle	Made of wax, waterproofing the leaf. It is secreted by cells of the upper epidermis.
upper epidermis	These cells are thin and transparent to allow light to pass through. No chloroplasts are present. They act as a barrier to disease organisms.
palisade mesophyll	The main region for photosynthesis. Cells are columnar (quite long) and packed with chloroplasts to trap light energy. They receive carbon dioxide by diffusion from air spaces in the spongy mesophyll.
spongy mesophyll	These cells are more spherical and loosely packed. They contain chloroplasts, but not as many as in palisade cells. Air spaces between cells allow gaseous exchange – carbon dioxide to the cells, oxygen from the cells during photosynthesis.
vascular bundle	This is a leaf vein made up of xylem and phloem. Xylem vessels bring water and minerals to the leaf. Phloem vessels transport sugars and amino acids away (this is called translocation).
lower epidermis	This acts as a protective layer. Stomata are present to regulate the loss of water vapour (this is called transpiration). It is the site of gaseous exchange into and out of the leaf.
stomata	Each stoma is surrounded by a pair of guard cells. These can control whether the stoma is open or closed. Water vapour passes out during transpiration. Carbon dioxide diffuses in and oxygen diffuses out during photosynthesis.

Test yourself

7 **a** Figure 6.23 is a section through a photosynthesising leaf.
On the diagram, label a palisade cell, a spongy mesophyll cell and a lower epidermal cell.

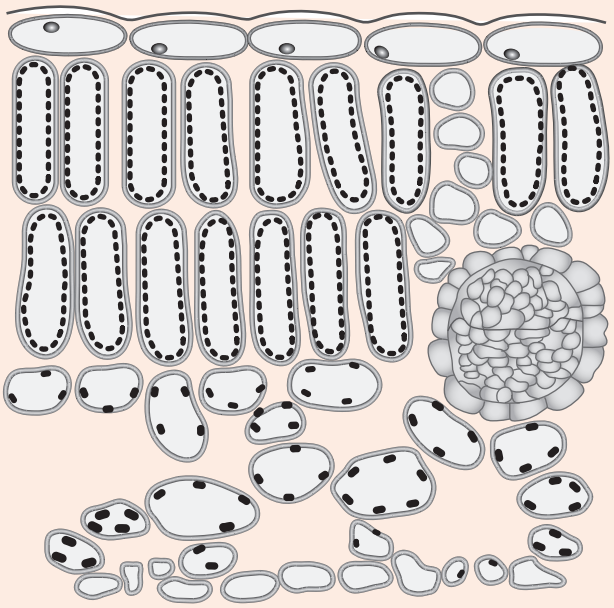
b Complete the table to state which of these cells would photosynthesise most rapidly, least rapidly and not at all. Explain your answers.

Type of leaf cell	Would the cell photosynthesise most rapidly, least rapidly or not at all?	Reason
lower epidermal cell		
palisade cell		
spongy mesophyll cell		

8 **a** State the source of energy for a photosynthesising plant.

b State the chemical process that provides a plant with energy to carry on all other living activities.

9 Look at Figure 6.22. Explain why photosynthesis does not take place in the cells of the upper epidermis.



▲ **Figure 6.23** Section through a photosynthesising leaf

Mineral nutrition

FOCUS POINT

★ Why are nitrate and magnesium ions important for plants?

Plants need a supply of nitrate ions (NO_3^-) for making amino acids (Chapter 4). Amino acids are important because they are joined to make proteins. These are needed to make the enzymes and cytoplasm of the cell. Nitrates are absorbed from the soil by the roots.

Plants also need magnesium ions (Mg^{2+}) to make chlorophyll, the photosynthetic pigment in chloroplasts. The plant gets its magnesium in mineral ions from the soil (see the salts listed under 'Water cultures' below).

Going further

Sources of mineral elements and effects of their deficiency

Nitrates and magnesium ions are often called mineral ions, or mineral elements. If the soil does not contain one of the mineral ions, the plants can show deficiency symptoms.

Many slow-growing wild plants do not show any deficiency symptoms even on poor soils. However, fast-growing crop plants will show clear deficiency symptoms. These will vary depending on the species of plant. If the plant has a shortage of nitrate ions, it shows stunted growth. The stem becomes weak. The lower leaves become yellow and die, and the upper leaves become pale green. If the plant has a shortage of magnesium, it will not be able to make chlorophyll. The leaves turn yellow from the bottom of the stem upwards (a process called chlorosis). Farmers and gardeners can recognise these symptoms and make sure the missing minerals are replaced, for example, by adding the correct fertiliser to the soil.

Plants absorb ions from the soil to get the mineral elements they need. For example, if a plant needs potassium (K) and nitrogen (N) it can absorb the ions of the salt potassium nitrate (KNO_3). Ions like this come from rocks that have been broken down to form the soil. They are continually being taken up from the soil by plants or washed out of the soil by rain. One way they are replaced is from the dead remains of plants and animals. When these organisms die and their bodies decay, the salts they contain are released back into the soil. There is a description of this process for nitrates in Chapter 19, 'Nutrient cycles'.

In arable farming (the term arable means land which is cultivated to grow crops on), the ground is ploughed and whatever is grown is removed. There are no dead plants left to decay so the mineral ions are not replaced. The farmer must replace them by spreading animal manure, sewage sludge or measured quantities of artificial fertilisers over the land.

Three manufactured fertilisers that are commonly used are ammonium nitrate, superphosphate and compound NPK, which contains nitrogen, phosphorus and potassium.

Water cultures

You can show the importance of some of the mineral elements by growing plants in water cultures. A full water culture is a solution containing the salts that provide all the necessary elements for healthy growth:

- potassium nitrate for potassium and nitrogen
- magnesium sulfate for magnesium and sulfur
- potassium phosphate for potassium and phosphorus
- calcium nitrate for calcium and nitrogen.

A green plant can use these elements, as well as the carbon dioxide, water and sunlight needed for photosynthesis, to make all the substances it needs to stay healthy.

Some areas of horticulture, for example, growing crops in a glasshouse, use water cultures widely. Sage plants can be grown with their roots in flat polythene tubes. The correct water culture solution is pumped along these tubes (Figure 6.24). The advantage of this method is that the yield is increased and there is no need to sterilise the soil each year to kill pests. This method is called hydroponics, or soil-less culture.

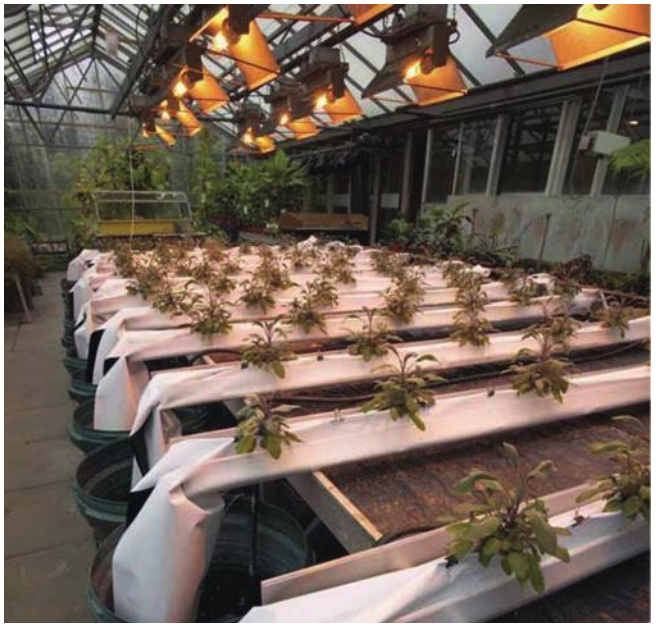


Figure 6.24 Soil-less culture. The sage plants are growing in a nutrient solution circulated through troughs of polythene

Test yourself

10 Figure 6.25 shows the increased yield of winter wheat in response to adding more nitrogenous fertiliser.

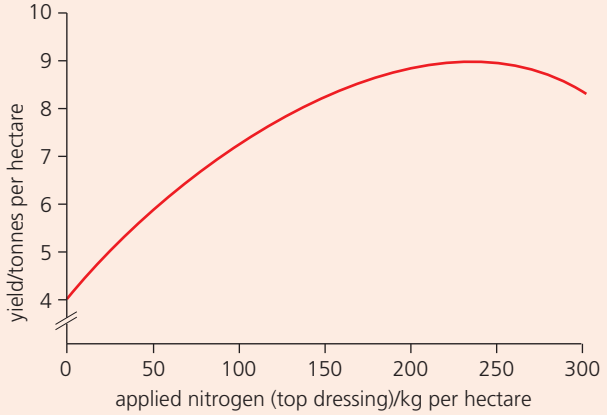


Figure 6.25 Increased wheat yield in response to nitrogenous fertiliser

Calculate how much extra wheat is produced per hectare.

- **a** If the applied nitrogen is doubled from 50 to 100 kg per hectare.
- **b** If the applied nitrogen is doubled from 100 to 200 kg per hectare.
- **c** Suggest what sort of calculations a farmer would need to make before deciding to increase the applied nitrogen from 150 to 200 kg per hectare.

11 What additional substance does the plant need to make proteins?

Revision checklist

After studying Chapter 6 you should know and understand the following:

- ✔ Photosynthesis is the process by which plants make their food.
- ✔ During photosynthesis, carbon dioxide and water are combined to make glucose.
- ✔ To do this, plants need energy from sunlight, which is absorbed by a green pigment, chlorophyll.
- ✔ Chlorophyll converts light energy to chemical energy.
- ✔ The word equation to show photosynthesis is

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

- ✔ The balanced chemical equation for photosynthesis is

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

- ✔ Plant leaves are adapted for the process of photosynthesis by being broad and thin, with many chloroplasts in their cells.
- ✔ From the glucose made by photosynthesis, a plant can make all the other substances it needs, provided it has a supply of mineral ions like nitrates.
- ✔ In daylight, respiration and photosynthesis will be taking place in a leaf; in darkness, only respiration will be taking place.
- ✔ In daylight, a plant will be taking in carbon dioxide and giving out oxygen.
- ✔ In darkness, a plant will be taking in oxygen and giving out carbon dioxide.
- ✔ Experiments to test photosynthesis are designed to exclude light, carbon dioxide or chlorophyll, to see if the plant can still produce starch.
- ✔ A starch test can be carried out to determine if photosynthesis has occurred in a leaf.
- ✔ The rate of photosynthesis may be limited by light intensity, carbon dioxide concentration and temperature. These are called limiting factors.
- ✔ Leaves have a structure which adapts them for photosynthesis.
- ✔ Plants need a supply of nitrate ions to make protein and magnesium ions to make chlorophyll.

Exam-style questions

1 A molecule of carbon dioxide enters a leaf cell at 4 p.m. and leaves the same cell at 6 p.m. Describe what could have happened to the carbon dioxide molecule during the 2 hours it was in the leaf cell. [3]

2 Complete the table to identify which gases you would expect a leaf to be taking in and giving out
- **a** in bright sunlight
- **b** in darkness. [4]

light conditions	gases taken in by the plant	gases given out by the plant
bright sunlight		
darkness		

3 Measurements on a leaf show that it is giving out carbon dioxide and taking in oxygen. Does this prove that photosynthesis is *not* going on in the leaf? Explain your answer. [2]

4 With reference to photosynthesis, state the adaptations and functions of
- **a** the epidermis [2]
- **b** the mesophyll of a leaf. [2]

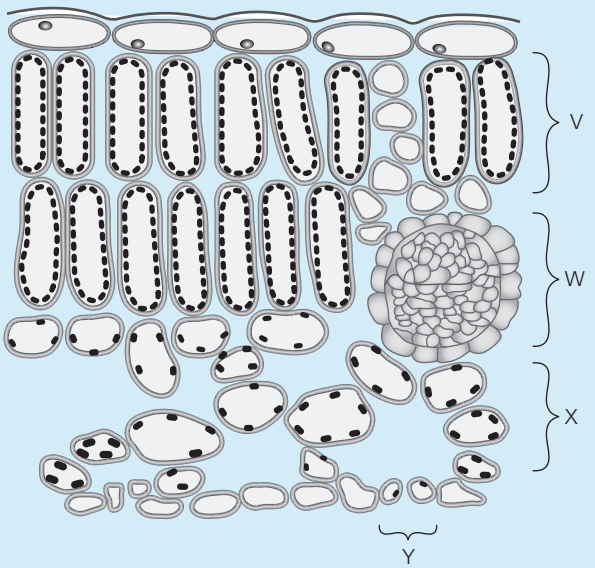
5 In some plants, the stomata close for a period at about midday. Suggest **one** advantage and **two** disadvantages of this to the plant. [3]

6 **a** Suggest how a floating pond plant, like duckweed, can survive without having its roots in soil. [1]

b Duckweed has stomata. Suggest where these would be found in a duckweed leaf. Explain your answer. [2]

7 Elements that are essential for plant growth are contained in nitrates and phosphates. They are found in freshwater, but phosphate is usually present in smaller amounts than nitrate. Nitrate is usually present in excess. However, because of the smaller amounts of phosphate in the water, it can be a limiting nutrient for water plants.
- **a** Explain why phosphate is described as a limiting nutrient for water plants. [2]
- **b** Suggest the effect of a small decrease in nitrate supply on water plants. Give a reason for your answer. [1]
- **c** State **two** factors, other than mineral ions or light, that can limit plant growth. [2]

8 The diagram shows a section through a leaf.
- **a** Identify the parts V, W, X and Y. [4]
- **b** Describe the main features and functions of each part. [8]



7 Transport in flowering plants

Focus

In Chapter 6 we explored the process of photosynthesis in plants and looked at ways of investigating what plants need to make their own food. In this chapter you will find out how the plant moves materials around. Most animals have a pump called a heart to move essential chemicals around the body. How do plants get their requirements from one place to another when they do not have a pump? Your knowledge of leaf structure will help you to understand what is going on in the plant.

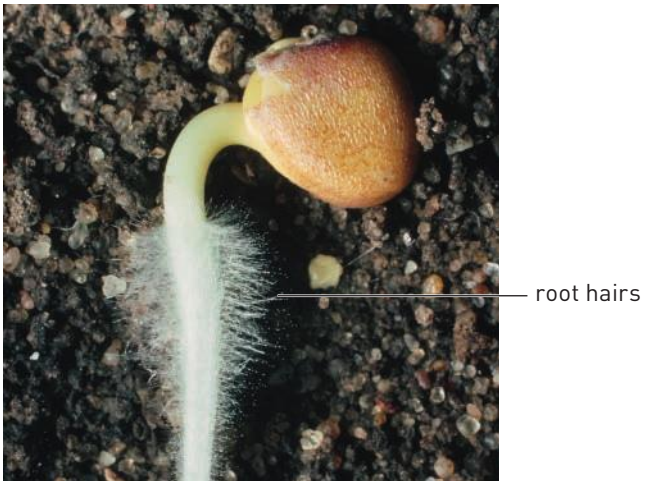
Water uptake

FOCUS POINTS

- ★ What do root hair cells look like and what are their functions?
- ★ What is the pathway taken by water through the plant?

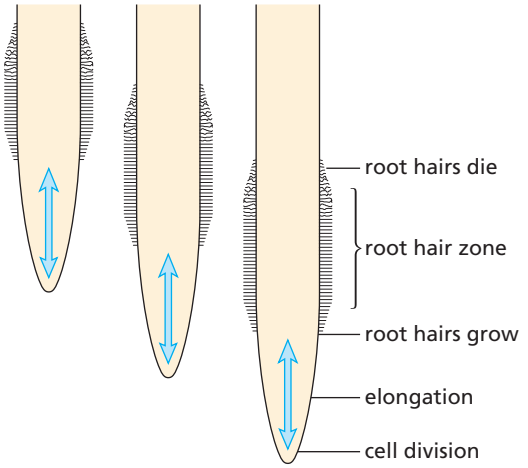
Root hair cells

In a region above the root tip, where the root has just stopped growing, the cells of the outer layer produce tiny, tube-like outgrowths called root hairs (Figure 7.3). These look like a white furry layer on the roots of seedlings if you grow them in moist air (Figure 7.1). In the soil, the root hair cells grow between the soil particles and stick closely to them. They provide a large surface area to take up water from the soil by osmosis and to absorb mineral ions by active transport (Chapter 3).



▲ **Figure 7.1** Root hairs (×5) as they appear on a root grown in moist air

Root hair cells only live for a short time. The region of root just below a root hair zone is producing new root hairs, while the root hairs at the top of the zone are shrivelling (Figure 7.2). Above the root hair zone, the cell walls of the outer layer become less permeable. This means that water cannot get in so easily.



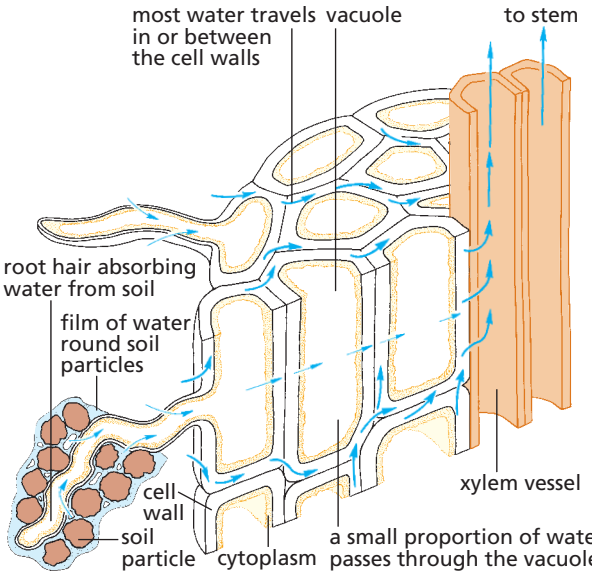
▲ **Figure 7.2** The root hair zone changes as the root grows

Uptake and transport of water and ions

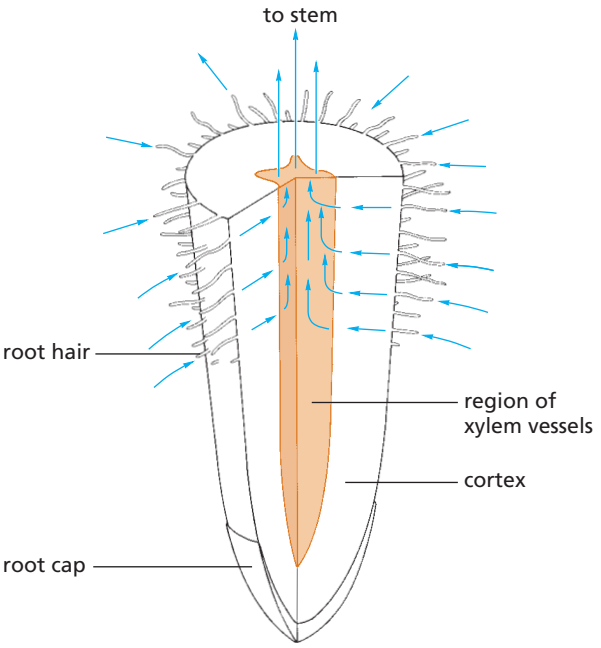
Scientists think that the water tension developed in the vessels by a rapidly transpiring plant (see next section) is enough to move water through the root from the soil. The water enters the root hair cells and is then passed on to cells in the root cortex. It enters the xylem vessels and moves up the stem and into the leaves. Here, the xylem passes along the midrib before branching into the leaf veins, arriving at the leaf mesophyll cells.

Scientists are still unsure of how the water passes through the cortex of the root, but Figure 7.3 shows possible routes. It is probably easier for the water to pass in or between the cell walls rather

than through the cytoplasm of each cell. Figure 7.4 summarises the movement of water from the soil to the stem of the plant.



▲ **Figure 7.3** The likely pathways of water through a root



▲ **Figure 7.4** Diagrammatic section of root to show passage of water from the soil

Practical work

Safety

- Eye protection must be worn.
- Take care using methylene blue – it can stain skin and clothes.

1 Transport in the vascular bundles

- Place the shoots of several leafy plants in a solution of 1% methylene blue. 'Busy Lizzie' (*Impatiens*) or celery stalks with leaves usually work well.
- Leave the shoots in the light for up to 24 hours.

Result

If you cut across some of the stems, you will see the dye in the vascular bundles (see Figure 7.6). You may also be able to see the blue dye in some of the leaf veins.

Interpretation

These results show that the dye travels up the stem in the vascular bundles. This suggests that water travels the same way. Closer study would show that they travel in the xylem vessels.

2 Transport of water in the xylem

- Cut three leafy shoots from a deciduous tree or shrub. Each shoot should have about the same number of leaves.
- On one twig remove a ring of bark about 5 mm wide, about 100 mm up from the cut base.
- With the second shoot, smear a layer of petroleum jelly over the cut base so that it blocks the vessels. The third twig is a control.
- Place all three twigs in a jar with some water. The water level must be below the region from which you removed the ring of bark.
- Place the twigs in direct sunlight.

Result

After an hour or two, you will probably find that the twig with blocked vessels is starting to wilt. The other two twigs should still have firm leaves.

Interpretation

When you removed the bark, this included the phloem. This has not stopped water from reaching the leaves. However, blocking the xylem vessels has stopped the water getting to the leaves. So, the vessels of the xylem are the most likely route for water passing up the stem.

Practical work questions

1 Suggest how you could use a stain to show that the petals of a daffodil flower contain xylem vessels.

2 For experiment 1, draw a large diagram of the cut stem. Label the xylem vessels (where the blue dye can be seen).

3 Explain why experiment 2 shows that water is not transported in the phloem vessels.

Test yourself

1 Place the parts of a root in the correct order to outline the passage of water into the plant:
cortex cells mesophyll cells root hair cells xylem

2 Describe the path taken by a water molecule from the soil until it reaches a mesophyll cell of a leaf to be made into glucose.

Stem and root structure

FOCUS POINTS

★ What are the functions of xylem and phloem?
★ How does the structure of xylem vessels relate to their function?

Going further

Before looking into detail at stem and root structure, it is worth looking at the relationship between these parts and the whole plant.

A young sycamore plant is shown in Figure 7.5. It is like many flowering plants because it has a **root system** below the ground and a shoot above ground. The shoot consists of an upright stem with leaves and buds. The buds on the side of the stem are called lateral buds. When they grow, they will produce branches. The bud at the tip of the shoot is the terminal bud and when it grows it will continue the growth of the stem upwards. The lateral buds and the terminal buds may also produce flowers.

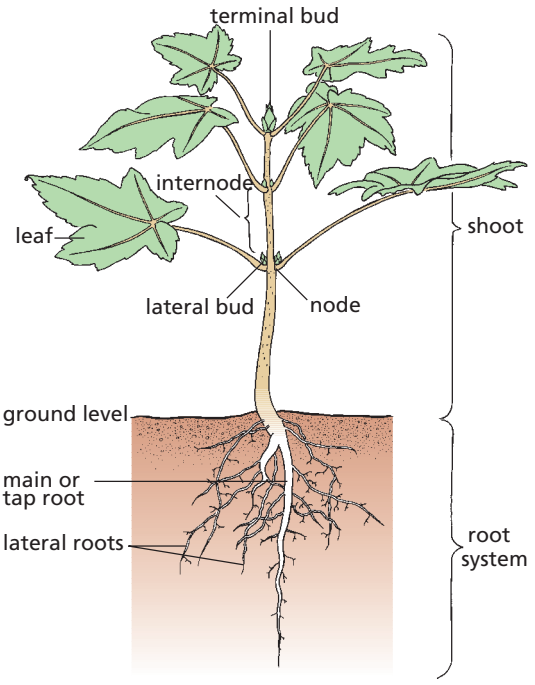
The region of stem from which leaves and buds arise is called a node. The region of stem between two nodes is the internode.

The leaves make food by photosynthesis (Chapter 6) and pass it back to the stem.

The stem carries this food to all parts of the plant that need it and carries water and dissolved mineral salts from the roots to the leaves and flowers.

The stem also supports and spaces out the leaves so that they can receive sunlight and absorb carbon dioxide, which they need for photosynthesis.

An upright stem also holds the flowers above the ground, helping **pollination** of the plant by insects or the wind (see 'Sexual reproduction in plants' in Chapter 16). A tall stem may help in seed dispersal later in the life cycle of the plant.



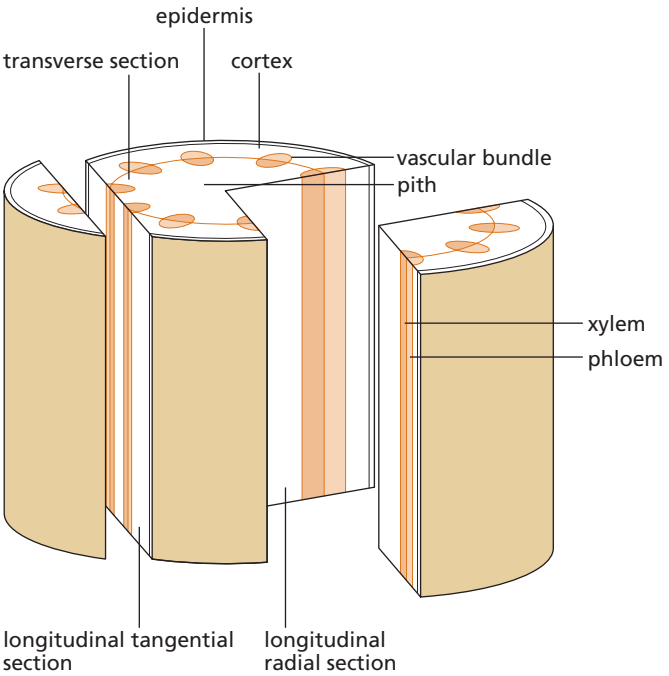
▲ **Figure 7.5** Structure of a typical flowering plant

The roots anchor the plant in the soil and stop it falling over or being blown over by the wind. They also absorb the water and mineral ions that the plant needs for making food in the leaves. A third function is sometimes the storage of food made by the leaves.

The structure of a leaf has already been described in Chapter 6. Xylem and phloem are present in the midrib of the leaf, as well as in the leaf veins. These features are identified in Chapter 6, Figures 6.17 and 6.18.

Stem

In Figure 7.6 a stem is shown cut across (transversely) and down its length (longitudinally) to show its internal structure.



▲ **Figure 7.6** Structure of a plant stem

Epidermis

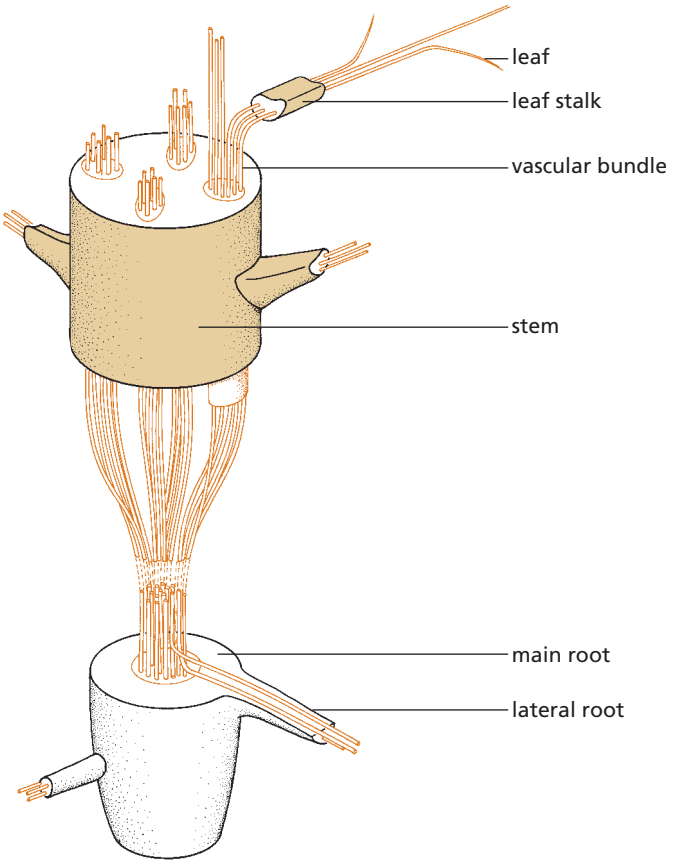
Like the leaf epidermis, this is a single layer of cells that helps to keep the shape of the stem and cuts down the loss of water vapour. There are stomata in the epidermis, which allow the tissues inside to take up oxygen and get rid of carbon dioxide.

Vascular bundles

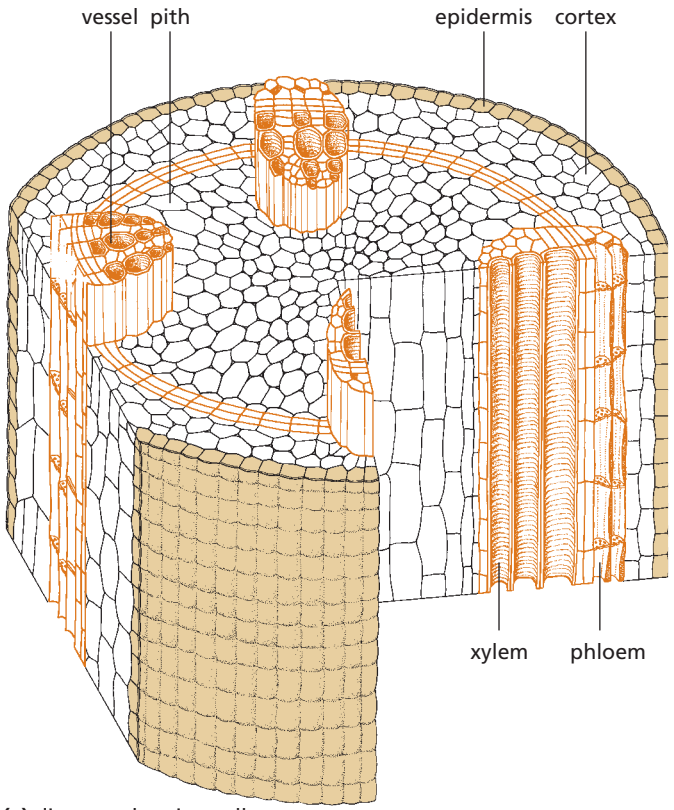
These are made up of groups of specialised cells that carry water, dissolved mineral salts and food up or down the stem. The vascular bundles in the roots, stem, leaf stalks and leaf veins all join to form a transport system through the whole plant (Figure 7.7). The two main tissues in the vascular bundles are called xylem and phloem (Figure 7.8). Food substances (sucrose and amino acids) travel in the phloem; water and mineral ions travel mainly in the xylem. The cells in each tissue form elongated tubes called vessels (in the xylem) or sieve tubes (in the phloem) and they are surrounded and supported by other cells. The xylem also helps to support the plant.

Vessels

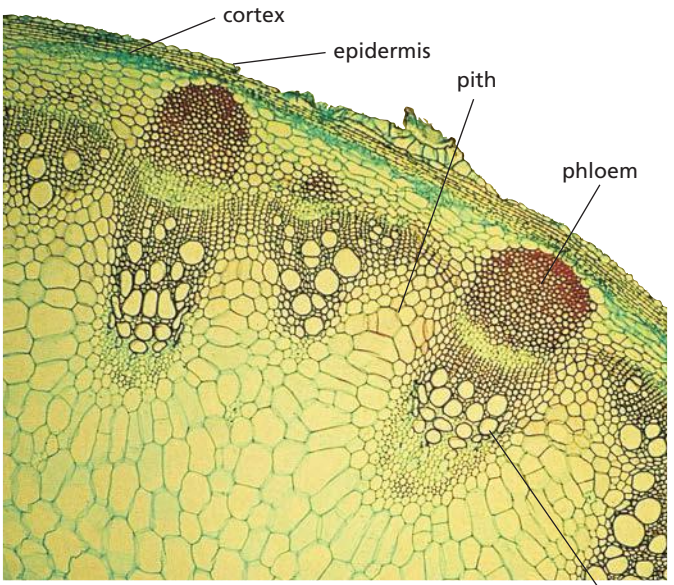
The cells in the xylem that carry water become vessels. A vessel is made up of a series of long cells joined end to end (Figure 7.9). A vessel is hollow and has no cell contents. Once a region of the plant has stopped growing, the end walls of these cells are digested away to form a long, continuous tube (Figure 7.8(c)). The cell walls become thickened and impregnated with a substance called lignin, which makes the cell wall very strong and impermeable. These lignified cell walls prevent the free passage of water and nutrients, so the cytoplasm dies. This does not affect the passage of water in the vessels. Xylem also contains many long, lignified supporting cells called fibres.



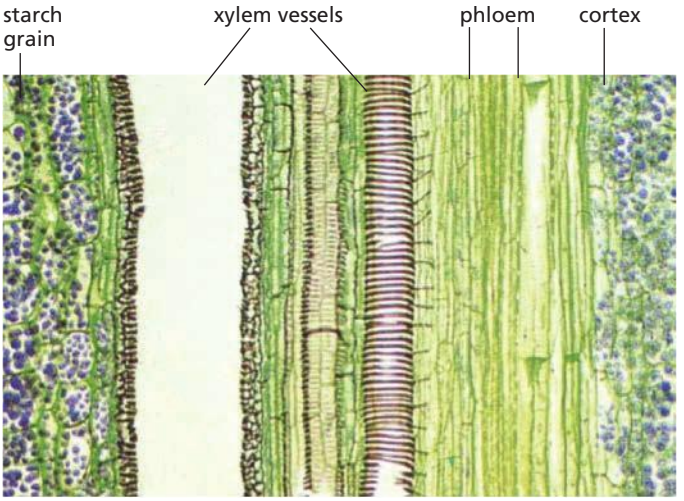
▲ **Figure 7.7** Distribution of veins from root to leaf



(a) diagram showing cells



(b) transverse section through sunflower stem (x40)

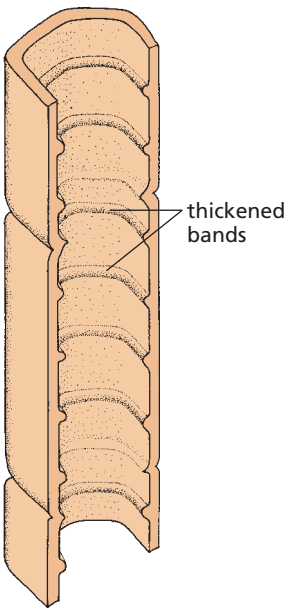


(c) longitudinal section through sunflower stem (x200)

▲ **Figure 7.8** Structure of plant stem

Cortex

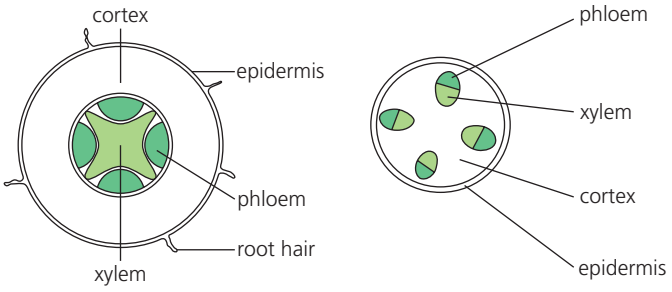
The tissue between the vascular bundles and the epidermis is called the **cortex**. Its cells often store starch. In green stems, the outer cortex cells contain chloroplasts and make food by photosynthesis. Within the cortex is the central tissue of the stem, called pith.



▲ **Figure 7.9** Cells forming a xylem vessel

Root

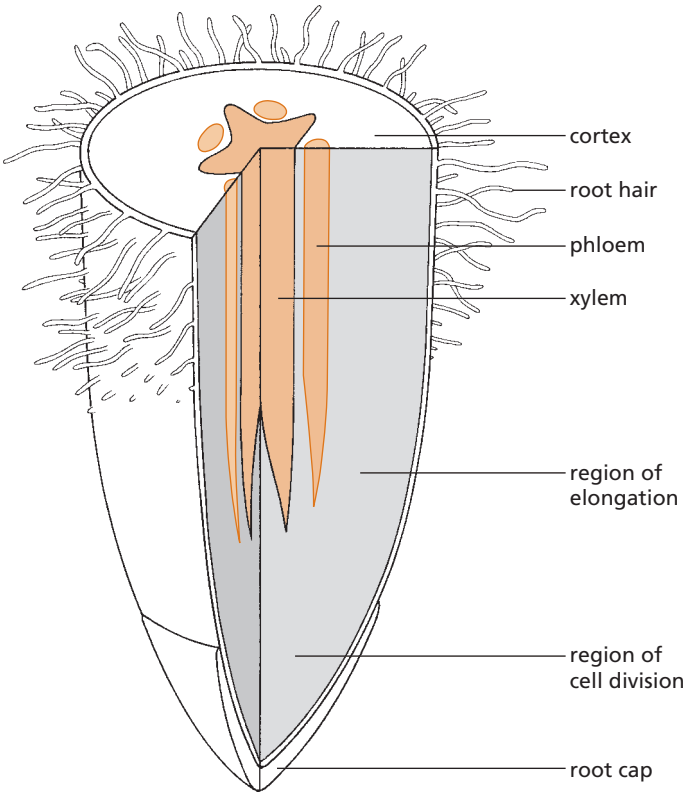
The internal structure of a typical root is shown in Figure 7.11. The vascular bundle is made up of groups of specialised cells in the centre of the root. They conduct water, dissolved mineral ions and food (Figure 7.10). This is different from the stem, where the vascular bundles form a cylinder in the cortex.



▲ **Figure 7.10** Section through a root (left) and stem (right)

Outer layer

There is no distinct epidermis in a root. At the root tip there are several layers of cells forming the root cap. These cells are being replaced as fast as they are worn away when the root tip is pushed through the soil.



▲ **Figure 7.11** Root structure

Test yourself

3 Describe where you would find xylem vessels in the stem, root and leaves of a plant.

4 A student is given a cylindrical structure cut from part of a plant. With the aid of a microscope or hand lens, how could they tell whether it was a piece of stem or a piece of root?

5 Name the tissues you would expect to find in a vascular bundle.

6 Describe how the structure of the xylem is related to its function.

Transpiration and translocation

FOCUS POINTS

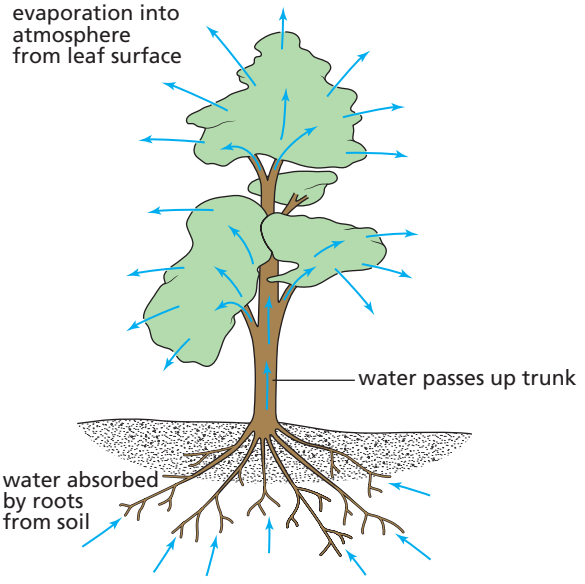
- ★ What is transpiration?
- ★ What is the mechanism for moving water through the plant?
- ★ What are the effects of varying temperature, light intensity, humidity and wind speed on transpiration rate?
- ★ How and why does wilting occur?
- ★ What is translocation?
- ★ What are sources and sinks?

Transpiration

Key definitions

Transpiration can be defined as the loss of water vapour from leaves.

Water evaporates from the surfaces of the spongy mesophyll cells of the leaves into the air spaces. It then diffuses out of the leaves through the stomata as water vapour. Water transpiring from the leaves causes suction, which pulls water up the stem (Figure 7.12). The water travels up the xylem vessels in the vascular bundles (see Figure 7.7, page 104) and this flow of water is called the transpiration stream.



▲ **Figure 7.12** The transpiration stream

Practical work

Safety

- Eye protection must be worn.

3 Demonstrating water loss by a plant

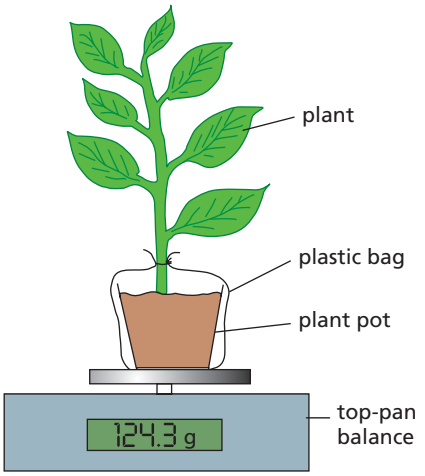
- The apparatus shown in Figure 7.13 is called a weight **potometer**. Set up a well-watered potted plant by placing the pot in a plastic bag. Seal around the stem of the plant using an elastic band or string. Then place the plant on a top-pan balance and record its mass. After a measured time period, for example, 24 hours, re-weigh the plant and calculate the difference in mass. Knowing the time that has passed, you can calculate the rate of mass loss per hour. Repeat the process, exposing the plant to different environmental conditions, such as higher temperature, light intensity, humidity or wind speed.

Results

You will find that the plant loses mass over the measured time period. Increases in temperature and wind speed result in larger rates of loss of mass.

Interpretation

As the roots and soil surrounding the plant have been sealed in a plastic bag, you can assume that any mass lost must be due to the evaporation of water vapour from the stem or leaves (transpiration). Increases in temperature, light intensity and wind speed all cause the rate of transpiration to increase, so the rate of loss of mass from the plant also increases. An increase in humidity will reduce the rate of loss of mass. This is because it reduces transpiration.



▲ **Figure 7.13** A weight potometer

Practical work question

4 Describe how an increase in temperature results in an increase in loss of mass from the plant.

Worked example

A potted plant was set up as described on the previous page, weighed and left for 24 hours before being re-weighed.

Results

Mass of potted plant at start	350.0 g
Mass of potted plant after 24 hours	335.0 g

The change in mass = mass at start – mass after 24 hours
= 350.0 – 335.0 = 15.0 g

If you are going to collect results for a plant kept in different conditions and want to compare them, you really need to start each time with a plant that weighs the same. However, in practice this can be very difficult. Instead, you can calculate the percentage change in mass. This takes into account any differences in the starting mass so that you can make a valid comparison of the changes in mass.

To calculate the percentage change in mass, we need to use the equation:

$$\frac{\text{change in mass}}{\text{mass at start}} \times 100$$

With any percentage change calculation you always use the same formula:

$$\frac{\text{change}}{\text{original}} \times 100$$

So, with our data:

$$= \frac{15.0}{350.0} \times 100 = 4.3\ \%$$

When doing calculations like this one, always keep the same number of decimal places in your answer as the number in the data you are given.

Tasks

1 A potted plant set up as described in the weight potometer experiment weighed 360.0g. After 24 hours it weighed 338.4 g.
   a Calculate the percentage loss in mass.
   b Calculate the rate of loss of mass per hour.

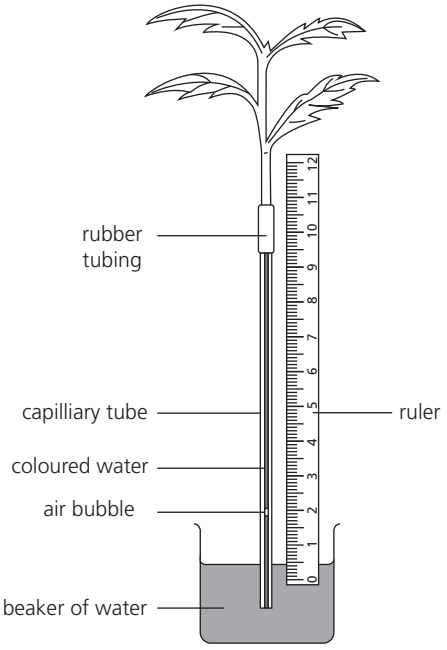
Practical work

Safety

- Eye protection must be worn.

4 Rates of water uptake in different conditions

- The apparatus shown in Figure 7.14 is called a simple potometer. It is designed to measure the rate of uptake of water in a cut shoot.
- The plant stem can be attached directly to a length of capillary tubing with a short section of rubber tubing. This is easiest to do in a bowl of water.
- While still in the water, squeeze the rubber tubing to force out any air bubbles.
- Remove the potometer from the water and rub a piece of filter paper against the end of the capillary tubing. This will introduce an air bubble. The capillary tubing does not need to have a scale: you can clamp a ruler next to the tubing.
- Record the distance moved by the bubble over a measured period of time. Then place the end of the capillary tubing in a beaker of water and squeeze out the air bubble.
- Introduce a new air bubble as previously described and take further readings. In this way obtain the average of three readings.



▲ **Figure 7.14** A simple potometer

- The conditions can now be changed in one of the following ways:
  1. Move the apparatus into sunlight or under a fluorescent lamp.
  2. Blow air past the shoot with an electric fan or a hair dryer on a cold setting, or fan it with an exercise book.
  3. Cover the shoot with a plastic bag.
  4. Move the apparatus to a hotter place.
- After each change of condition, take three more readings of the rate of uptake. Notice whether they suggest an increase or a decrease in the rate of transpiration.

Results

1. An increase in light intensity should make the stomata open and cause the water in the leaf to evaporate faster, resulting in more rapid transpiration.
2. Moving air should increase the rate of transpiration and, therefore, the rate of uptake.
3. The plastic bag will cause a rise in humidity round the leaves and reduce transpiration.
4. The rise in temperature will increase the rate of transpiration, and, therefore, the rate of uptake.

Interpretation

Ideally, you should change only one condition at a time. If you took the experiment outside, you would be changing the light intensity, the temperature and the air movement. When the rate of uptake increased, you would not know which of these three changes was mainly responsible.

To obtain reliable results, you need to keep taking readings until three of them are nearly the same. A change in conditions may take 10 or 15 minutes before it produces a new, steady rate of uptake. In practice, you may not have time to do this, but even your first three readings should show a trend towards increased or decreased uptake.

Practical work question

5. Suggest why it is necessary to clear the air bubble out of the tubing after each reading.

Going further

Limitations of the potometer

Although we use the potometer to compare rates of transpiration, it is really the rates of uptake that we are observing. Not all the water taken up will be transpired; some will be used in photosynthesis; some may be absorbed by cells to increase the water pressure inside them. However, these quantities are very small compared with the volume of water transpired and they can be ignored.

The rate of uptake of a cut shoot may not reflect the rate in the intact plant. If the root system were present, it might resist the flow of water or it could help the flow because of its root pressure.

Rate of transpiration

Transpiration is the evaporation of water from the leaves, so any change that increases or reduces evaporation will have the same effect on transpiration.

Humidity

If the air is very humid, i.e. contains a large amount of water vapour, it can accept very little more from the plants and so transpiration slows down. In dry air, the diffusion of water vapour from the leaf to the atmosphere will be rapid.

Air movements

In still air, the region round a transpiring leaf will become saturated with water vapour so that no more can escape from the leaf. In these conditions, transpiration would slow down. In moving air, the water vapour will be swept away from the leaf as fast as it diffuses out. This will speed up transpiration.

Temperature

Warm air can hold more water vapour than cold air. So, evaporation or transpiration will take place more rapidly into warm air.

Also, when the Sun shines on the leaves they will absorb heat as well as light. This warms them up and increases the rate of evaporation of water.

Investigations into the effect of some of these conditions on the rate of transpiration are described earlier in this chapter.

Water loss from leaves

The cells in part of a leaf blade are shown in Figure 7.16. As explained in 'Osmosis' in Chapter 3, the cell sap in each cell is applying a turgor pressure outwards on the cell wall. This pressure forces some water out of the cell wall, evaporating into the air space between the cells. The water vapour passes through the air spaces in the mesophyll and out of the stomata by diffusion. Each leaf contains many air spaces in the spongy mesophyll and the air becomes saturated with water vapour. There are hundreds of stomata, mainly on the lower epidermis of the leaf, allowing water vapour to diffuse from a high concentration in the air spaces into the atmosphere (which has a lower concentration of water vapour, unless the humidity is high).

The cell walls that are losing water in this way replace it by getting water from the nearest vein. Most of this water travels along the cell walls without going inside the cells (Figure 7.17). Thousands of leaf cells are evaporating water like this: their surfaces make a very large surface area. More water is taken in from the xylem vessels in the veins to replace the evaporated water. As a result, water is pulled through the xylem vessels and up the stem from the roots. This transpiration stream is strong enough to pull up water 50 metres or more in trees (Figure 7.15).

▲ **Figure 7.15** Yellow meranti tree. Some of these Malaysian trees are over 80 metres tall. Transpiration from their leaves pulls hundreds of litres of water up the trunk

Water movement in the xylem

You may have learned that you cannot draw water up by suction to a height of more than about 10 metres. Many trees are taller than this, but they can draw up water effectively. How can this happen? In long vertical columns of water in very thin tubes, the attractive forces between the water molecules result in cohesion (the molecules stick together). The attractive forces are greater than the forces trying to separate them. So, the transpiration

stream is pulling up thin threads of water, which resist the tendency to break.

However, there are still problems. It is likely that the water columns in some of the vessels do have air pockets in them and yet the total water flow is not affected.

Evidence for the pathway of water

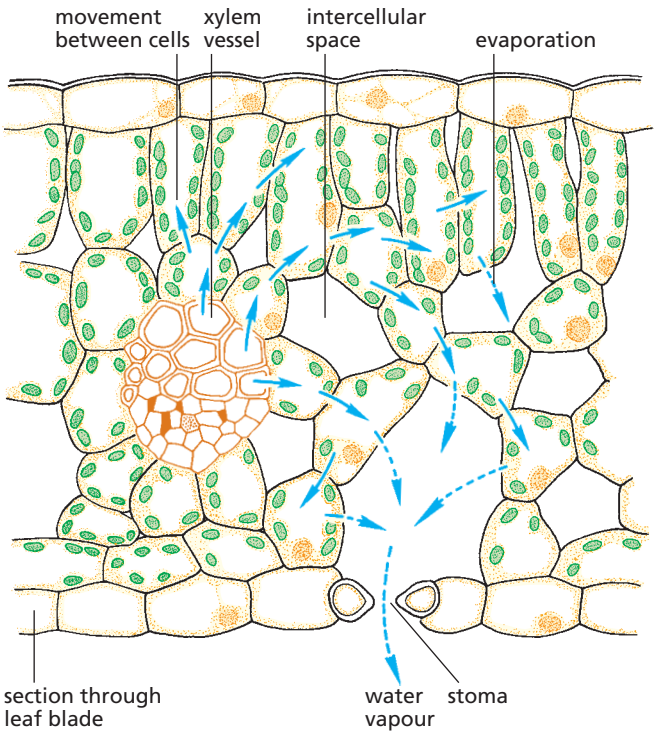
The experiment on page 102 uses a dye to show that in a cut stem the dye, and so also the water, travels in the vascular bundles. Closer study using a microscope would show that it travels in the xylem vessels.

Removal of a ring of bark (which includes the phloem) does not affect the passage of water along a branch. Killing parts of a branch by heat or poisons does not stop the flow of water, but anything that blocks the vessels does stop the flow.

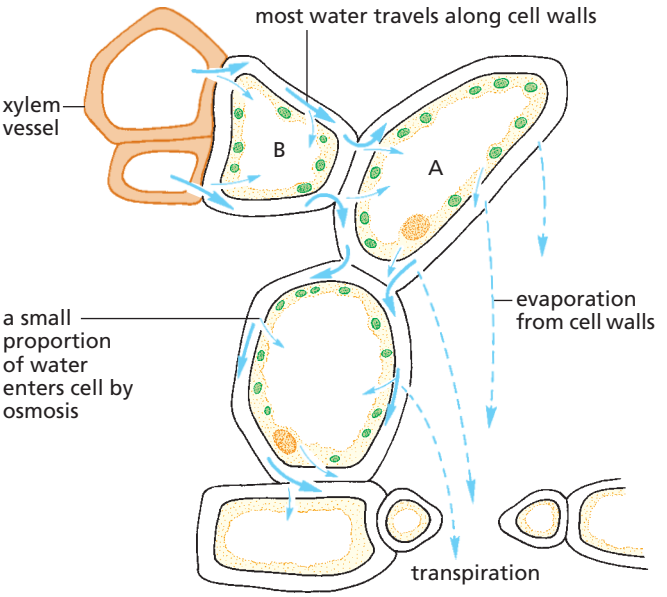
The evidence all points to the non-living xylem vessels as the main route by which water passes from the soil to the leaves.

Wilting

In addition to the water passing along the cell walls, a small amount will pass right through the cells. When leaf cell A in Figure 7.17 loses water, its turgor pressure will fall. This fall in pressure allows the water in the cell wall to enter the vacuole and so restore the turgor pressure. In conditions of water shortage, cell A may be able to get water by osmosis from cell B more easily than B can get it from the xylem vessels. In this case, all the mesophyll cells will be losing water faster than they can absorb it from the vessels, and so the leaf will wilt (see 'Osmosis' in Chapter 3). Water loss from the cell vacuoles results in the cells losing their turgor and becoming flaccid. A leaf with flaccid cells will be limp and the stem will droop. A plant that loses water to this extent is said to be wilting (see Figure 3.13 on page 49).



▲ **Figure 7.16** Movement of water through a leaf



▲ **Figure 7.17** Probable pathway of water through leaf cells

Importance of transpiration

On a hot day a tree may draw up hundreds of litres of water from the soil (Figure 7.15). Most of this water evaporates from the leaves; only a small percentage is kept for photosynthesis and to maintain the turgor of the cells. Scientists are not sure how this great loss of water is an advantage to the plant. A rapid water flow may be needed to obtain enough mineral ions, which are in very dilute solution in the soil. Evaporation may also help to cool the leaf when it is exposed to strong sunlight.

An argument against the first possibility is that, in some cases, an increased transpiration rate does not increase the uptake of minerals.

The second possibility, the cooling effect, might be very important. A leaf exposed to direct sunlight will absorb heat and the increase in temperature may kill the cytoplasm. Water evaporating from a leaf absorbs its latent heat and cools the leaf down. This is probably one benefit of transpiration. However, there are plants whose stomata close at around midday, reducing transpiration significantly. How do these plants avoid overheating?

Many biologists think that transpiration is an unavoidable consequence of photosynthesis. In order to photosynthesise, a leaf needs to take in carbon dioxide from the air. The pathway that allows carbon dioxide in will also let water vapour out, whether the plant needs to lose water or not. It is likely that plants need to keep a careful balance between the optimum intake of carbon dioxide and a damaging loss of water.

The role of stomata

The opening and closing of stomata can be triggered by a number of factors, including light intensity, carbon dioxide concentration and humidity. These factors interact with each other. For example, a rise in light intensity will increase the rate of photosynthesis and so lower the carbon dioxide concentration in the leaf. These are the conditions you would expect to affect the opening of the stomatal pore if the stomata are to control the balance between loss of water vapour and uptake of carbon dioxide.

The stomata also react to water stress, i.e. if the leaf is losing water by transpiration faster than it is being taken up by the roots. Before wilting happens, the stomata start to close. Although they do not prevent wilting, the stomata do seem to delay the start of it.

Practical work

Safety

- Eye protection must be worn.

5 To find which surface of a leaf loses more water vapour

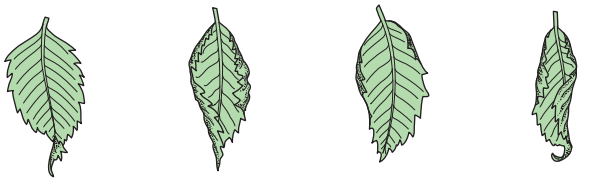
- Cut four leaves of about the same size from a plant (do not use an evergreen plant). Protect the bench with newspaper or a paper towel and then treat each leaf as follows:
  - **a** Smear a thin layer of petroleum jelly on the lower surface.
  - **b** Smear petroleum jelly on the upper surface.
  - **c** Smear petroleum jelly on both surfaces.
  - **d** Leave both surfaces free of petroleum jelly.
- Place a little petroleum jelly on the cut end of the leaf stalk. Set up two retort stands with a string tied between them (like a washing line). Tie cotton threads to the leaf stalks and hang the four leaves from the string. Leave them for several days.

Result

You will find that all the leaves have shrivelled and curled up to some extent. However, the ones that lost most water are the most shrivelled (Figure 7.18).

Interpretation

The petroleum jelly prevents evaporation. The untreated leaf and the leaf with its upper surface sealed show the greatest amount of shrivelling, so leaves lose most water by evaporation from the lower surface.



(a) lower surface **(b)** upper surface **(c)** both surfaces **(d)** neither surface

▲ **Figure 7.18** The results of evaporation from leaves given different treatments

More accurate results may be obtained by weighing the leaves at the start and the end of the experiment. It is best to place the leaves from the whole class into groups according to how they have been treated and weigh each group. Ideally, the weight loss should be converted to a percentage of the initial weight (see the worked example on page 108 for an explanation).

The results of the experiment can be linked to the numbers of stomata on the upper and lower epidermis. You can do this by painting clear nail varnish or a skin treatment like *Germolene New-Skin* over each surface and allowing it to dry. Peel the varnish off and view it under the microscope. You should be able to see the outlines of the guard cells and count them.

Practical work question

6 Explain why the application of petroleum jelly onto the surface of the leaf prevents transpiration.

Test yourself

7 Two weight potometers were set up with similar plants (see Figure 7.13). One plant was kept in cool conditions. The other was placed near a source of heat.
The plants were weighed each day for four days.

time/ days	mass of plant in cool conditions/g	mass of plant in hot conditions/g
0	290	286
1	280	262
2	275	235
3	270	228
4	265	225

a Plot the results on a graph.
b **i)** Describe the results.
ii) Write a conclusion.
c A student suggested that a fairer comparison of the results would be to calculate percentage changes in mass. Explain why the suggestion is true for this set of data.
d Explain why the pots of the plants were placed in sealed plastic bags.

8 Study the leaves in Figure 7.18.
a Place the leaves in order of water loss, from least water loss to most water loss.
b With reference to stomata, explain the results of the investigation.

9 Explain what would happen to the leaves of a plant that was losing water by transpiration faster than it was taking it up from the roots.

Translocation

The xylem sap is always a very dilute solution, but the phloem sap may contain up to 25% of dissolved solids, most of which is sucrose and amino acids. There is plenty of evidence to support the view that sucrose, amino acids and other substances are transported in the phloem.

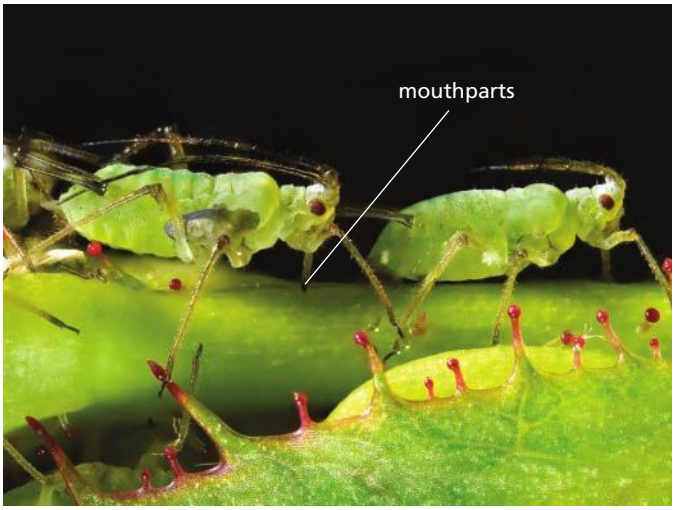
Key definitions

Translocation is the movement of sucrose and amino acids in the phloem.

The movement of water and mineral ions in the xylem is always upwards, from soil to leaf. However, the solutes in the phloem may be travelling up or

down the stem. The carbohydrates made in the leaf during photosynthesis are converted to sucrose and carried out of the leaf (the **source**) to the stem. From here, the sucrose may pass upwards to growing buds and fruits or downwards to the roots and storage organs (**sink**). All parts of a plant that cannot photosynthesise will need a supply of nutrients transported in the phloem. Substances can be travelling upwards and downwards in the phloem at the same time.

Some insects feed using syringe-like mouthparts. These pierce the stems of plants to remove liquid from the phloem vessels. Figure 7.19 shows aphids feeding on a rose plant. The pressure of sucrose solution in the phloem can be so great that it is forced through the gut of the aphid and droplets of the sticky liquid ooze from its anus.



▲ **Figure 7.19** Aphids feeding on a rose plant

Test yourself

10 A complete ring of bark cut from around the circumference of a tree trunk causes the tree to die. The xylem continues to carry water and salts to the leaves, which can make all the substances needed by the tree. Explain why the tree dies.

11 Describe where you would find phloem vessels in a leaf.

12 Make a list of all the non-photosynthetic parts of a plant that need a supply of sucrose and amino acids.

Going further

Some parts of a plant can act as a source and a sink at different times during the life of a plant. For example, while a bud containing new leaves is forming it would require nutrients and so it acts as a sink. However, once the bud has burst and the leaves are photosynthesising, the region would act as a source, sending newly synthesised sugars and amino acids to other parts of the plant. Similarly, the new tuber of a potato plant would act as a sink while it was growing, storing sugars as starch. (Starch is a good storage molecule because it is insoluble and quite compact.) However, once the buds on the tubers start to grow, the stored starch is converted to sucrose, a soluble nutrient. This will be passed to these buds from the tuber. So, the tuber becomes the source. The shoots will also eventually become sources, after they have broken through the soil and have produced new leaves that can photosynthesise. Bulbs, such as those of the daffodil and lily (see 'Asexual reproduction' in Chapter 16), act in the same way, although some store sugars as well as starch.

Substances do travel in the sieve tubes of the phloem, but we do not fully understand the mechanism by which they are moved. We do know that translocation depends on active transport, which requires energy from respiration, because anything that prevents cell metabolism, for example, poisons or high temperatures, also stops translocation (see 'Active transport' in Chapter 3 and 'Respiration' in Chapter 10).

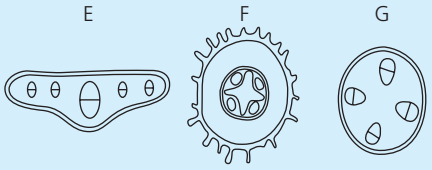
Revision checklist

After studying Chapter 7 you should know and understand the following:

- ✔ The xylem vessels in the veins carry water and mineral ions up the stem to the leaves.
- ✔ The phloem in the veins carries food (sucrose and amino acids) up or down the stem to wherever it is needed.
- ✔ The position of xylem in the root and shoot helps the stem to withstand sideways bending and the root to resist pulling forces.
- ✔ Xylem vessels have a structure that adapts them to carry water.
- ✔ The root hairs make very close contact with soil particles and are the main route by which water and mineral ions enter the plant.
- ✔ The large surface area provided by root hairs increases the rate of absorption of water (osmosis) and mineral ions (active transport).
- ✔ Water travels through the plants through root hair cells, root cortex cells, xylem and mesophyll cells.
- ✔ The mechanism by which water moves upwards in the xylem.
- ✔ The pathway of water through a plant can be traced using a suitable stain.
- ✔ Transpiration is the loss of water vapour from leaves.
- ✔ The large surface area provided by cell surfaces, interconnecting air spaces and stomata in the leaf encourages the evaporation of water.
- ✔ Water vapour diffuses out of the leaf through the stomata.
- ✔ The rate of transpiration is affected by wind speed and temperature.
- ✔ The rate of transpiration is also affected by humidity.
- ✔ Wilting occurs when the volume of water vapour lost by leaves is greater than that absorbed by roots.
- ✔ Translocation is the movement of sucrose and amino acids in phloem from sources to sinks.
- ✔ Sources are the parts of plants that release sucrose or amino acids, sinks are the parts of plants that use or store sucrose or amino acids.

Exam-style questions

1 The diagrams show sections through three parts of a plant.



a Identify E, F and G. [3]

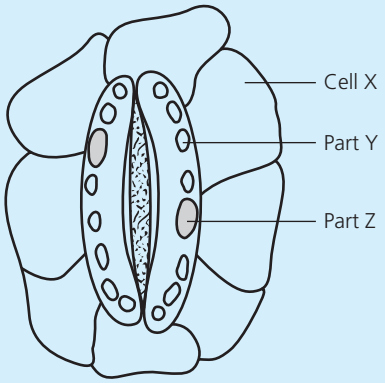
b Make drawings of the parts E, F and G. On **each** of your drawings, label an example of xylem and phloem. [6]

c Describe the role of

i) the surface of F in the process of transpiration [2]

ii) the phloem in E. [3]

2 The diagram shows a pair of guard cells on the lower surface of a leaf.



a Identify cell X and cell parts Y and Z. [3]

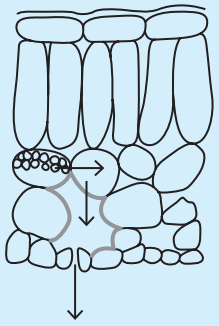
b The guard cells are shown as they appeared in the dark.

i) Draw them as they would appear in the light. [2]

ii) Label the stoma. [1]

c Explain the advantage to the plant of the stomata being closed at night. [2]

3 The diagram shows a section through part of a leaf. The arrows represent the movement of water.



a On the diagram, label **three** different types of cells. [3]

b With reference to cells and regions of the leaf, describe the process of transpiration. [6]

c State the changes in conditions that would increase the rate of transpiration. [3]

4 **a** Define the term *tissue*. [2]

b Complete the table about plant tissues and their functions. [3]

name of plant tissue	function
phloem	
	transport of water
	absorption of water from the soil

5 **a** Describe how you could use a small plant to compare the rate of transpiration in still and windy conditions. [6]

b Predict the results you would expect to obtain. [2]

6 Describe and explain how

a water moves into the stem of a plant [6]

b a named plant with a storage organ gains sugars. [4]

7 **a** Define the term *transpiration*. [2]

b Describe how xylem vessels are adapted to their role. [3]

c State **two** ways in which transpiration is different from translocation. [2]

d Explain how wilting occurs. [4]

8 Describe and explain the effect of the following on the rate of transpiration in a plant:

a decreasing humidity [2]

b decreasing temperature. [2]

8 Human nutrition

Focus

In Chapter 6 you found out how plants get their nutrition. You have seen how the equation for photosynthesis tells you all about what the plant needs and what it produces as waste products. You also know what happens if plants have a deficiency of key mineral ions. So, what about human nutrition? What do we need to stay healthy? How does our body process the food we eat? What happens if we lack key foodstuffs in our diet? In this chapter we will find the answers to these questions.

Diet

FOCUS POINTS

- ★ What is a balanced diet?
- ★ What are the main sources of nutrients in our diet and why are they important?
- ★ What are the causes of scurvy and rickets?

The need for food

All living organisms need food. An important difference between plants and animals is that green plants can make food in their leaves, but animals need to take it in 'ready-made' by eating plants or the bodies of other animals. In all plants and animals, food is used as follows:

For growth

It gives the substances needed for making new cells and tissues.

As a source of energy

Energy is needed for the chemical reactions that take place in living organisms to keep them alive. When food is broken down during respiration (see Chapter 10), the energy from the food is used for chemical reactions like building large molecules (Chapter 4). In animals the energy is also used for activities like movement, the heartbeat and nerve impulses. Humans, like other mammals, use energy to maintain their body temperature.

For replacement of worn and damaged tissues

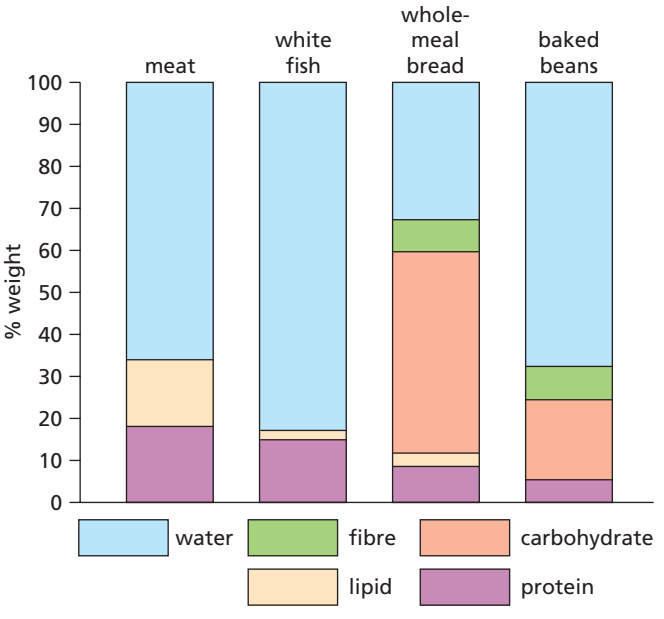
We need the substances provided in food to replace the millions of red blood cells that break down each day, to replace the skin that is worn away and to repair wounds.

Balanced diets

Key definitions

A **balanced diet** is a diet that contains all the essential nutrients in the correct proportions to maintain good health. The nutrients needed are carbohydrate, lipid, protein, vitamins, mineral salts, fibre (roughage) and water.

A balanced diet must contain enough carbohydrates and lipids to meet our energy needs. It must also contain enough protein to provide the essential amino acids to make new cells and tissues for growth or repair. The diet must also contain vitamins and mineral ions, plant fibre (roughage) and water. The composition of four food samples is shown in Figure 8.1.



▲ **Figure 8.1** An analysis of four food samples

Note: The percentage of water includes any salts and vitamins. There are wide variations in the composition of any given food sample according to its source and the method of preservation and cooking. 'White fish' (e.g. cod and tilapia) contains less than 3% lipid, whereas rohu and mackerel contain more than 10%. Rawas (Indian salmon) contains 12% lipid. White bread contains only 2–3% fibre. When you fry food it increases its lipid content.

Going further

Energy requirements

We can get energy from carbohydrates, fats and proteins. The cheapest energy-giving food is usually carbohydrate; the greatest amount of energy is available in fats. Proteins give about the same energy as carbohydrates but they are expensive. Whatever mixture of carbohydrate, fat and protein makes up the diet, the total energy must be enough

- to keep our internal body processes working (e.g. heart beating, breathing action)
- to keep up our body temperature
- to allow us to work and do other activities.

The amount of energy that can be gained from food is measured in calories or joules. One gram of carbohydrate or protein can provide us with 16 or 17 kJ (kilojoules). A gram of lipid can give 37 kJ. We need to obtain about 12 000 kJ of energy each day from our food. Table 8.1 shows how this figure is calculated. However, the figure depends on our age, occupation and activity (Figure 8.2). A person who does hard manual work, like digging, will use more energy than someone who sits in an office. Similarly, someone who takes part in a lot of sport will need more energy input than someone who does not do much physical exercise.

Females usually have lower energy requirements than males. One reason for this is that females have, on average, a lower body mass than males, which requires less energy.

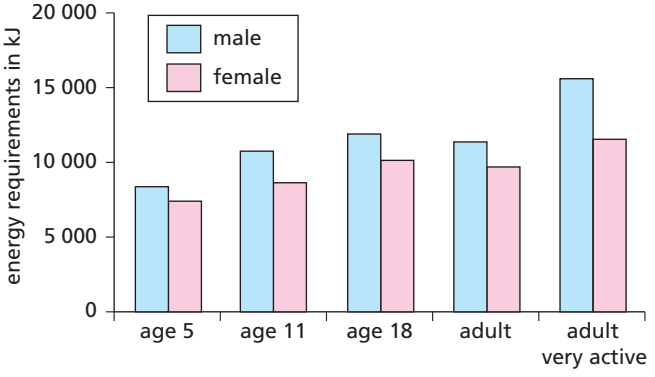
As children grow, their energy need increases because of the energy demands of growth and the extra energy needed to maintain their body temperature. However, metabolism tends to slow down with age once we become adults, so the need for energy reduces. This is because of a gradual loss of muscle tissue.

▼ **Table 8.1** Energy requirements in kJ

8 hours asleep	2 400
8 hours awake; relatively inactive physically	3 000
8 hours physically active	6 600
Total	12 000

From the table, you can see that we still need energy while we are sleeping. We use this energy to maintain the circulation, breathing, body temperature, brain function and important chemical processes in the liver and other organs.

If the diet includes more food than we need to supply the energy demands of the body, the extra food is stored as glycogen in the liver, or as fat below the skin and in the abdomen.



▲ **Figure 8.2** The changing energy requirements with age and activity

Classes of food

There are three classes of food: carbohydrates, proteins and lipids. The chemical structure of these substances is described in Chapter 4. These substances are present in a balanced diet and do not normally have to be taken in separately. A summary of the three classes of food and their sources is shown in Table 8.3.

Carbohydrates

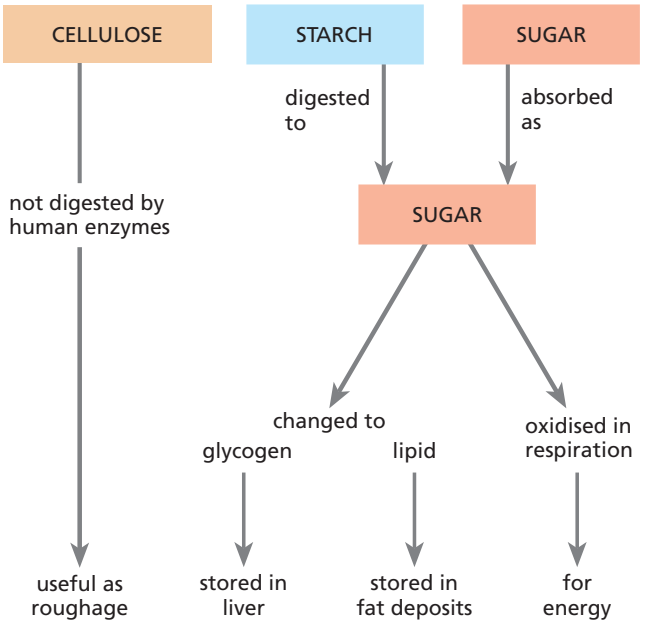
Sugar and starch are important carbohydrates in our diet. Potatoes, bread, maize, rice and other cereals are a good source of starch. Sucrose (table sugar) is the most common sugar in our diet. It is present in drinks and many prepared foods like jam, biscuits and cakes. Glucose and fructose are sugars that are found in many fruits and some vegetables.

Although all foods provide us with energy, carbohydrates are the cheapest and most readily

available source of energy. They contain the elements carbon, hydrogen and oxygen (e.g. glucose is $C_6H_{12}O_6$). When carbohydrates are oxidised to release energy by respiration, they are broken down to carbon dioxide and water (Chapter 10). One gram of carbohydrate can give, on average, 16 kilojoules (kJ) of energy (see practical work 'Energy from food' on page 124).

If we eat more carbohydrates than we need for our energy requirements, the excess is converted in the liver to either glycogen or lipid. The glycogen is stored in the liver and muscles; the lipid is stored in fat deposits in the abdomen, round the kidneys or under the skin (Figure 8.3).

The cellulose in the cell walls of all plant tissues is a carbohydrate. We probably get little nourishment from cellulose because we cannot digest it, but it is important in the diet as fibre (roughage). This helps to keep our digestive system healthy.



▲ **Figure 8.3** Digestion and use of carbohydrate

Lipids

Animal lipids are found in meat, milk, cheese, butter and egg-yolk. Sources of plant fats are oils in fruits (e.g. palm oil) and seeds (e.g. sunflower seed oil). They are used for cooking and making margarine.

Lipids are used in the cells of the body to make part of the cell membrane and other membrane systems. Lipids can also be oxidised in respiration to carbon dioxide and water. When used to provide energy in this way, 1 g of lipid gives 37 kJ of energy. This is more than twice as much energy as can be gained from the same weight of carbohydrate or protein.

Lipids can be stored in the body in fat deposits, providing a way of long-term energy storage. The fatty tissue (see Chapter 14, Figures 14.22 and 14.23) forms a layer under the skin. It can reduce heat loss from the body if its blood supply is limited.

Proteins

Proteins are a key part of the diet because they supply the amino acids needed to build up our own body structures. Lean meat, fish, eggs, milk and cheese are important sources of animal protein. All plants contain some protein, but soybeans, seeds like pumpkin, and nuts are the best sources (see Table 8.2).

▼ **Table 8.2** Comparing the protein content of foods (various sources)

Food	Protein content/g per 100 g
soybeans	35
chicken breast	31
pumpkin seeds	30
peanuts	26
fish, e.g. rawas	24
bacon	20
cheese, e.g. paneer	19
Tofu	18
chicken sausage	17
Quorn sausage	14
eggs	13
falafel	13
wheat flour	13
yoghurt	4

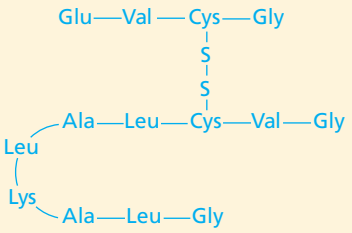
When we digest proteins they give us amino acids, which we need to build cells and tissues, for example, skin, muscle, blood and bones. These proteins also form part of the cytoplasm and enzymes of cells and tissues. Carbohydrates and lipids cannot do this, so it is essential that we have some proteins in our diet. An example of how the body uses amino acids is shown in Figure 8.4.

The amino acids that are not used for making new tissues cannot be stored, but the liver removes their amino ($—NH_2$) groups and changes the residue to glycogen. The glycogen can be stored or oxidised to provide energy (Chapter 10). One gram of protein can provide 17 kJ of energy.

Chemically, proteins are different from both carbohydrates and lipids because they contain nitrogen and sometimes sulfur as well as carbon, hydrogen and oxygen.

(a) part of a plant protein of 14 amino acids

(b) digestion breaks up protein into amino acids



(c) our body builds up the same 14 amino acids but into a protein it needs

key Ala = alanine, Gly = glycine, Leu = leucine
Cys = cysteine, Glu = glutamine, Lys = lysine,
Val = valine, S = sulfur atom

▲ **Figure 8.4** An example of the digestion and use of a protein molecule

Going further

Protein requirements

Estimates of how much protein we need have changed recently. A WHO/FAO/UNU report recommended that an average person needs 0.57 g protein for every kilogram of body weight. So, a 70 kg person would need 70 × 0.57 = 39.9, i.e. about 40 g protein per day.

We could get this by eating about 200 g lean meat or 500 g bread. However, to supply this much protein from potatoes you would need to eat 2 kg of the vegetables, and even this will not contain all the essential amino acids.

Vegetarian and vegan diets

There is relatively less protein in food obtained from plants than there is in animal products. Vegetarians and semi-vegetarians, who include dairy products, eggs and possibly fish in their diets, will obtain sufficient protein to meet their needs (Table 8.2). However, some vegetarian foods now contain relatively high proportions of protein: *Quorn* products (made from mycoprotein – obtained from fungi) can contain 14.5 g protein per 100 g, compared with 17.0 g protein per 100 g for chicken breast. Mycoprotein does not contain animal lipids. Vegans, who eat no animal products, need to make sure that their diets include a range of cereals, peas, beans and nuts to obtain all the essential amino acids to build their body proteins. Falafel is becoming increasingly popular in vegetarian and vegan diets. It is made of chickpeas, fava beans or both. It can contain 13.0 g protein per 100 g.

▼ **Table 8.3** Summary table for carbohydrates, lipids and proteins

Nutrient	Good food sources	Use in the body
carbohydrate	rice, potato, yam, cassava, bread, millet, sugary foods (cake, jam, honey)	storage; source of energy
lipids (oils are liquid at room temperature, but fats are solid)	butter, milk, cheese, egg-yolk, animal fat, groundnuts (peanuts)	source of energy (twice as much as carbohydrate); **insulation** against heat loss; some hormones; cell membranes; insulation of nerve fibres
protein	meat, fish, eggs, soya, groundnuts, milk, Quorn, cowpeas, falafel	growth; tissue repair; enzymes; some hormones; cell membranes; hair; nails; can be broken down to provide energy

Vitamins

All proteins are like each other in their chemical structure, as are all carbohydrates. However, vitamins are a group of organic substances that have a different chemical structure.

There are some features that are shared by all vitamins:

- They are not digested or broken down for energy.
- Usually, they are not built into the body structures.
- They are vital in small quantities for health.
- They are needed for chemical reactions in the cells, working with enzymes.

Plants can make these vitamins in their leaves, but humans have to eat plants or animals to get them ready-made.

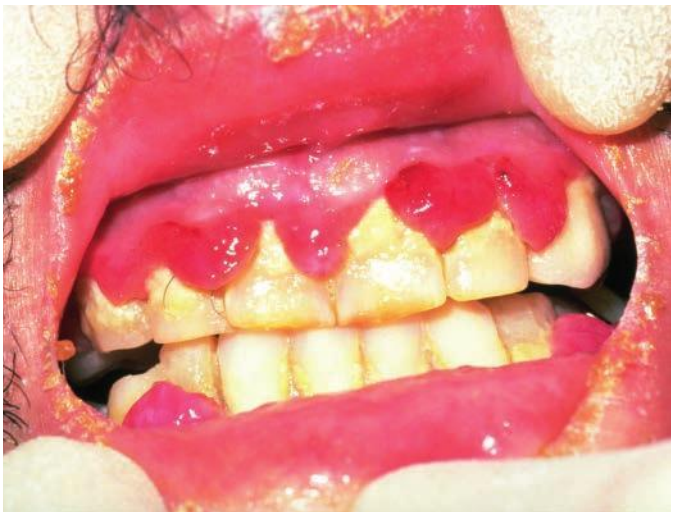
At least 15 vitamins have been identified and they are sometimes grouped into two classes: water-soluble and fat-soluble. The fat-soluble vitamins are mainly found in animal fats or vegetable oils, which is one reason why our diet should include some of these lipids. The water-soluble vitamins are present in green leaves, fruits and cereal grains.

See Table 8.4 for a summary of the details of vitamins C and D.

If any one of the vitamins is missing or deficient in the diet, a vitamin-deficiency disease may develop. The disease can be cured, at least in the early stages, simply by adding the vitamin to the diet.

Vitamin C

Vitamin C is present in all citrus fruits (oranges, lemons, limes), blackcurrants, guava, mango and cabbage. It is needed to maintain healthy skin and gums. A deficiency results in **scurvy** (Figure 8.5). Fibres in connective tissue of skin and blood vessels do not form properly, leading to bleeding under the skin. Other symptoms are feeling constantly tired, weak and irritable, with joint pains and swollen, bleeding gums. In severe cases, the teeth can fall out.



▲ **Figure 8.5** Symptoms of scurvy

Vitamin D

Vitamin D is the only vitamin that the body can make, when the skin is exposed to sunlight. However, for 6 months of the year (October to April), much of western Europe does not receive enough UV rays in sunlight to make vitamin D in the skin. So, many people living there are at risk of a vitamin D deficiency unless they get it in their diet. Also, people who have darker skin, like people of African, African-Caribbean and South Asian origin, are at risk because their skin reduces UV light absorption. Wearing clothes that cover the whole of the body also reduces the ability of the skin to benefit from UV light.

So, foods that provide vitamin D can be used in the diet to prevent vitamin D deficiency. These include oily fish like sardines and mackerel, fish-liver oil, butter, milk, cheese and egg-yolk. Also, many manufactured food products contain vitamin D supplements.

Vitamin D helps in the absorption of calcium and phosphorus through the gut wall. Bone is made of the mineral calcium phosphate. So, a lack of the vitamin results in bones not getting the calcium and phosphorus they need. When this happens, they become soft. The weight of the body can deform bones in the legs, causing the condition called **rickets** in children (Figure 8.6). Adults deficient in vitamin D are in danger of fracturing bones if they fall.

▲ **Figure 8.6** A child with rickets

▼ **Table 8.4** Vitamins

Name and source of vitamin	Importance of vitamin	Diseases and symptoms caused by lack of vitamin	Notes
Vitamin C; water-soluble: oranges, lemons, grapefruit, tomatoes, fresh green vegetables, potatoes	Prevents scurvy.	Fibres in connective tissue of skin and blood vessels do not form properly, leading to bleeding under the skin, particularly at the joints, swollen, bleeding gums and poor healing of wounds. These are all symptoms of scurvy (Figure 8.5).	May act as a catalyst in cell respiration. Scurvy is only likely to occur when fresh food is not available. Cows' milk and milk powders contain little vitamin C so babies may need other sources. Cannot be stored in the body; daily intake needed.
Vitamin D; fat-soluble: butter, milk, cheese, egg-yolk, liver, fish-liver oil	Prevents rickets.	Calcium is not deposited properly in the bones, causing rickets in young children. The bones remain soft and are deformed by the child's weight (Figure 8.6). Fractures are more likely in adults who are deficient.	Vitamin D helps the absorption of calcium from the intestine and the deposition of calcium salts in the bones. Natural lipids in the skin are changed to a form of vitamin D by sunlight.

Mineral ions

These are sometimes called mineral salts or minerals. Proteins, carbohydrates and fats provide the body with carbon, hydrogen, oxygen, nitrogen, sulfur and phosphorus, but there are several more elements that the body needs. These mineral ions are present in the food we eat.

Iron

Red blood cells contain the pigment haemoglobin (see 'Blood' in Chapter 11). Part of the haemoglobin molecule contains iron. This is needed to carry oxygen around the body. Millions of red blood cells break down each day. Their iron is stored by the liver and is used to make more haemoglobin. However, we lose some iron and it needs to be replaced through dietary intake.

Red meat, like liver and kidney, is the best source of iron in the diet. Other important sources are eggs, groundnuts, wholegrains, brown rice, spinach and other green vegetables.

Lack of iron in the diet can lead to iron-deficiency anaemia, which is a decrease in the number of red blood cells. Red blood cells, when mature, have no nucleus and this limits their life to about 3 months, after which they are broken down in the liver and replaced. Most of the iron is recycled, but some is lost in the **faeces** and needs to be replaced. Adults need to take in about 15 mg each day. Without sufficient iron, your body is unable to produce enough haemoglobin, the protein in red blood cells responsible for transporting oxygen to respiring tissues. This means that the oxygen-carrying capacity of the blood is reduced. Iron is also needed by the muscles and for enzyme systems in all the body cells. The symptoms of anaemia are feeling weak, tired and irritable.

Calcium

Calcium, in the form of calcium phosphate, is deposited in the bones and the teeth and makes them hard. It is present in blood plasma and plays a vital part in normal blood clotting (see 'Blood' in Chapter 11). Calcium is also needed for the chemical changes that make muscles contract and for the transmission of nerve impulses.

The best sources of calcium are milk (liquid, skimmed or dried) and cheese. Calcium is also present in small quantities in most foods as well as in 'hard' water.

Many calcium salts are not soluble in water and may pass through the **alimentary canal** without being absorbed. Simply increasing the calcium in the diet may not have much effect unless the calcium is in the right form, the diet is balanced and the intestine is healthy. Vitamin D and bile salts are needed for efficient absorption of calcium.

Lack of calcium in the diet can lead to rickets, where bones become easily broken. Other symptoms of calcium deficiency include weak and brittle nails and muscle cramps. As well as a lack of calcium-containing foods in the diet (milk, yoghurt, cheese and fish), a shortage of vitamin D results in poor absorption of calcium in the intestine.

▼ **Table 8.5** Minerals

Name and source of mineral	Importance of mineral	Diseases and symptoms caused by lack of mineral	Notes
calcium: milk, cheese, fish, some sources of water, e.g. 'hard' water	Needed to form healthy bones and for normal blood clotting.	Early signs are muscle aches, cramps and spasms, with numbness of hands, feet and around the mouth. Teeth and bones become soft and more easily breakable. Deficiency can lead to rickets (linked to vitamin D deficiency) and osteoporosis.	Most foods contain small amounts of calcium. A shortage of calcium in the diet at first results in calcium being removed from bones so no symptoms are apparent.
iron: red meat, liver, kidney, eggs, green vegetables (spinach, cabbage, cocoyam, groundnut leaves), chocolate	Needed for formation of haemoglobin in red blood cells (for transport of oxygen).	Anaemia. The symptoms are constant tiredness and a lack of energy.	In women, heavy periods can result in a loss of iron, which can result in anaemia.

Dietary fibre (roughage)

When we eat vegetables and other fresh plant material, we take in a large quantity of plant cells. The cell walls of plants are made of cellulose, but we do not have enzymes for digesting this substance. The result is that the plant cell walls reach the large intestine (colon) without being digested. This undigested part of the diet is called fibre or roughage.

The fibre increases the contents of the colon and help it to retain water. This softens the faeces and reduces the time needed for the undigested material to pass out of the body. Both effects help to prevent constipation and keep the colon healthy.

Most vegetables and whole cereal grains contain fibre, but white flour and white bread do not contain much. Good sources of dietary fibre are vegetables, fruit and wholemeal bread.

Water

About 70% of most tissue consists of water; it is a vital part of cytoplasm. The body fluids, blood and tissue fluid (Chapter 11) are composed mainly of water.

Digested food, salts and vitamins are carried around the body as a watery solution in the blood and excretory products like excess salt and urea are removed from the body in solution by the kidneys (Chapter 13). So, water is a solvent and a transport medium for these substances.

Digestion uses water in a chemical reaction to break down insoluble substances to soluble ones. These products then pass, in solution, into the bloodstream. Water plays a vital part in many reactions in cells, as a reactant and a solvent.

We lose water by evaporation, sweating, urinating and breathing, so we have to replace this by taking in water with the diet.

Test yourself

1 What sources of protein-rich foods are available to a vegetarian who
   a will eat animal products but not meat itself
   b will eat only plants and their products?
2 Explain why all diets must contain some protein.
3 Could you survive on a diet that contained no carbohydrate? Explain your answer.
4 How do proteins differ from lipids in
   a their chemical composition (Chapter 4)
   b their energy value
   c their function in the body?
5 Name two foods that contain high levels of
   a vitamin C
   b calcium.

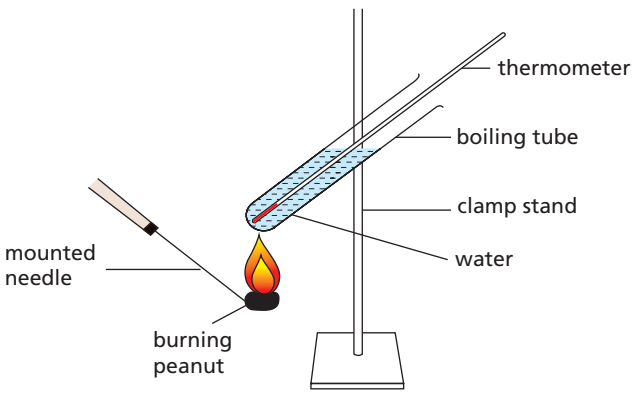
Practical work

Safety

- Eye protection must be worn.
- Take care using the needle to impale the peanut.
- Take care as the apparatus will get hot.
- ***CARE:* make sure that no students have nut allergies.**

1 Energy from food

- Set up the apparatus as shown in Figure 8.7.
- Use a measuring cylinder to place 20 cm^3 cold water in the boiling tube.
- Use a thermometer to measure the temperature of the water and make a note of it.
- Weigh a peanut (or other piece of dried food), fix it onto a mounted needle and heat it with the Bunsen flame until it begins to burn.
- As soon as it starts burning, hold the nut under the boiling tube so that the flames heat the water.
- If the flame goes out, do not use the Bunsen burner to re-light the food while it is under the boiling tube. Move the nut back to the Bunsen flame to start the nut burning again. Then hold the nut under the boiling tube as soon as it catches alight.
- When the nut has finished burning and cannot be lit again, gently stir the water in the boiling tube with the thermometer and record its new temperature.



▲ **Figure 8.7** Experiment to show the energy in food

- Calculate the rise in temperature by subtracting the first from the second temperature.
- Work out the quantity of energy transferred to the water from the burning peanut as follows:
  4.2 J raise 1 g water by 1 °C
  20 cm^3 cold water weighs 20 g
  The energy (in joules) released by the burning nut = rise in temperature × mass of water × 4.2
  Note: The value 4.2 in the equation is used to convert the answer from calories to joules, as the calorie is an obsolete unit.
- To calculate the energy from 1 g of nut, divide your answer by the mass of nut you used. This gives a value in J g^{-1}.
- The experiment can now be repeated using different sizes of nut, different varieties of nut, or other types of food. Remember to replace the warm water in the boiling tube with 20 cm^3 cold water each time.
- The experiment is not very accurate: compare the value you got with an official value (2 385 kJ per 100 g). There are plenty of websites with this sort of information if you use different nuts or other food. To make the comparison you may need to convert your energy value from joules to kilojoules (divide by 1 000) and to 100 g of the food (multiply by 100).

Practical work questions

1 Try to list some of the faults in the design of the experiment to explain the differences you find between your results and the official value.
2 Suggest where some of the heat is going.
3 Suggest ways of reducing this loss to make the results more accurate.

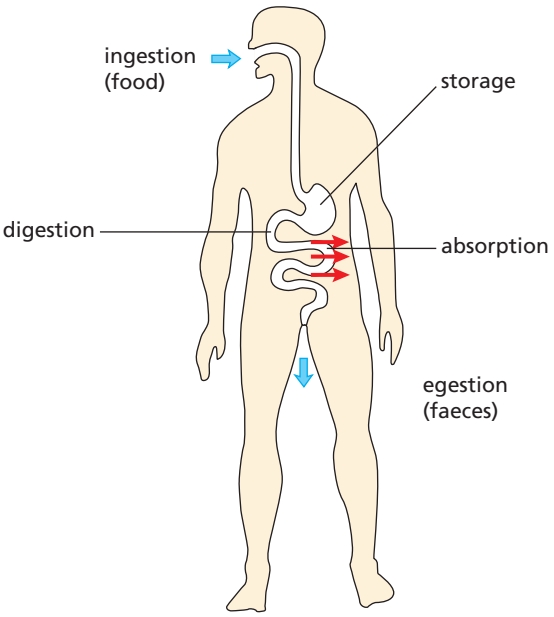
Human digestive system

Feeding involves taking food into the mouth, chewing it and swallowing it down into the stomach. However, for food to be of any use to the whole body it needs to be **digested**. This involves making the solid food soluble and reducing the size of the molecules. The soluble products then need to be **absorbed** into the bloodstream. The blood delivers dissolved food to the living cells of all the tissues and organs. This section describes how the food is digested and absorbed. Chapter 11 describes how the blood carries it around the body.

Going further

Regions of the digestive system and their functions

The alimentary canal is a tube running through the body in which food is digested. The soluble products are absorbed, and the indigestible food molecules are expelled (egested). A simplified diagram of the digestive system is shown in Figure 8.8.

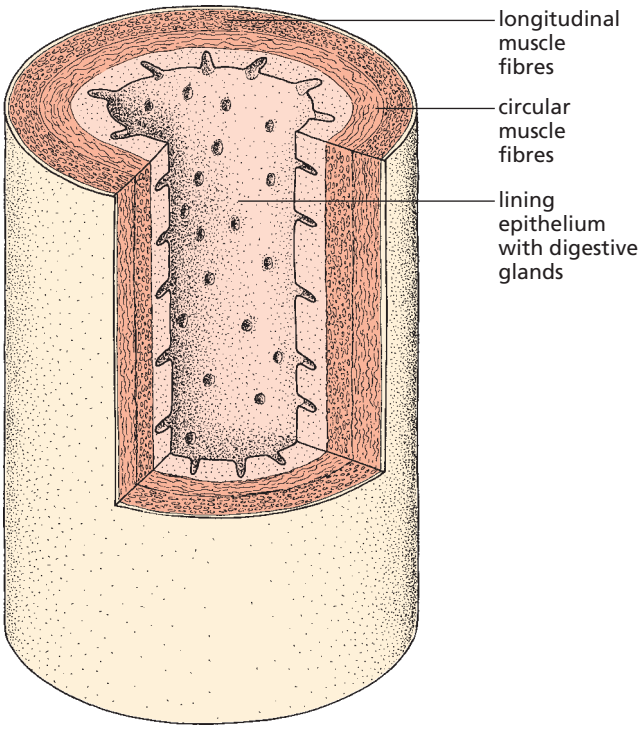


▲ **Figure 8.8** The digestive system (generalised)

The inside of the alimentary canal is lined with layers of cells called an epithelium. New cells in the epithelium are being produced all the time to replace the cells worn away by the movement of the food. There are also cells in the lining that produce **mucus**. Mucus is a slimy liquid that lubricates the lining of the tract and protects it from damage. Mucus may also protect the lining because it stops the **digestive enzymes** attacking it.

Some of the digestive enzymes are produced by cells in the lining of the alimentary canal, for example, the stomach lining. Others are produced by glands that are outside the digestive system. They release their enzymes through tubes (called **ducts**) into the alimentary canal (Figure 8.9). Two examples of digestive glands are the **salivary glands** and the **pancreas** (see Figure 8.14 on page 128).

The alimentary canal has many blood vessels in its walls, close to the lining. These bring oxygen to the cells and take away the carbon dioxide they produce. They also absorb the digested food from the alimentary canal.



▲ **Figure 8.9** The general structure of the alimentary canal

Test yourself

6 Where are enzymes produced?
7 State two functions of mucus in the alimentary canal.
8 Explain why the digestive system has many blood vessels in its walls.

Digestion

FOCUS POINTS

- ★ What is physical digestion?
- ★ Why is physical digestion important?
- ★ What are the different types of human teeth and their function?
- ★ What is the structure of a human tooth?
- ★ What is chemical digestion?
- ★ What is the role of chemical digestion?
- ★ What are the functions of the main parts of the digestive system?
- ★ Where in the digestive system are amylase, maltase, protease and lipase secreted, where do they act and what is their function?
- ★ What is the function of the hydrochloric acid in gastric juice?
- ★ How is starch digested in the digestive system?
- ★ How are proteins digested by proteases in the digestive system?
- ★ What does bile do in chemical digestion?

Key definitions

Physical digestion is the breakdown of food into smaller pieces without chemical change to the food molecules.

Chemical digestion is the breakdown of large molecules into small molecules.

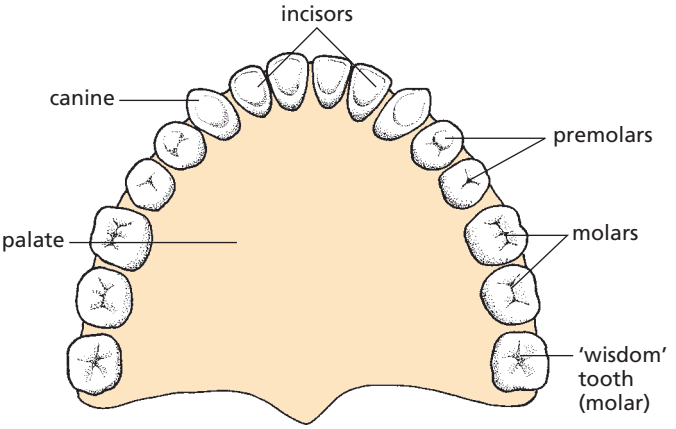
Physical digestion and teeth

The process of **physical digestion** mainly occurs in the mouth. The teeth are used to chew the food. This increases the surface area of food for the action of enzymes in **chemical digestion**. Other examples of physical digestion include the action of muscles in the stomach and the emulsification of fats by **bile**. These are described later in this chapter.

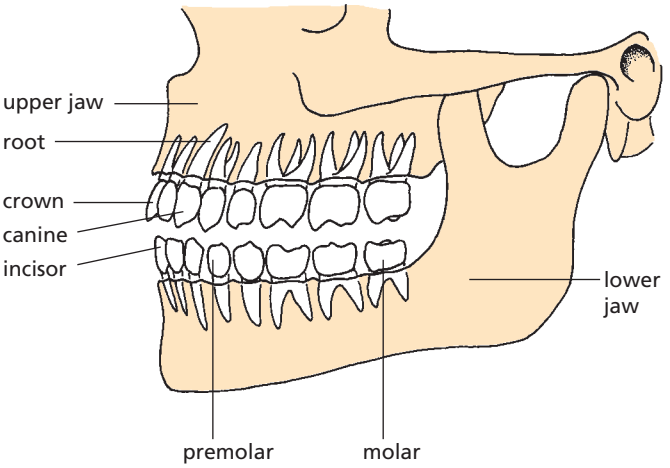
Humans are omnivores (organisms that eat animal and plant material). We have similar types of teeth as carnivores, but human teeth are not used for catching, holding, killing or tearing up prey, and we cannot crush bones. Figure 8.10 shows the position of teeth in the upper jaw and Figure 8.11 shows how they look in both jaws when seen from the side.

Table 8.6 gives a summary of the types of human teeth and their functions.

Our top incisors pass in front of our bottom incisors. They cut pieces off the food, for example, when biting into an apple or taking a bite out of a piece of toast.



▲ **Figure 8.10** Teeth in human upper jaw

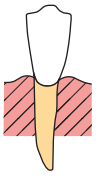
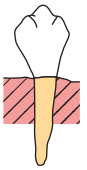
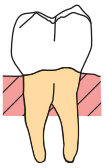


▲ **Figure 8.11** Human jaws and teeth

Our canines are more pointed than the incisors and are slightly larger. They behave like extra incisors.

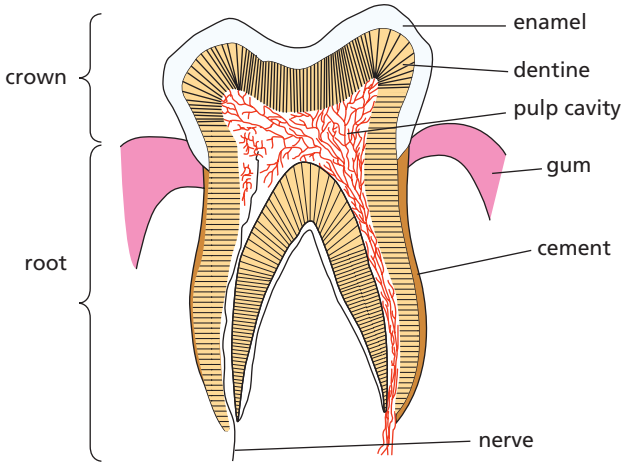
Our premolars and molars are similar in shape and function. Their knobbly surfaces, called cusps, meet when the jaws are closed. They crush the food into small pieces. Small particles of food are easier to digest than large pieces.

▼ **Table 8.6** Summary of types of human teeth and their functions

Type	Incisor	Canine	Premolar	Molar
Diagram				
Position in mouth	front	either side of incisors	behind canines	back
Description	chisel-shaped (sharp edge)	slightly more pointed than incisors	have two points (cusps); have one or two roots	have four or five cusps; have two or three roots
Function	biting off pieces of food	similar function to incisors	tearing and grinding food	chewing and grinding food

Tooth structure

The part of a tooth that is visible above the gum line is called the crown. The gum is tissue that overlays the jaws. The rest, embedded in in the jaw bone, is called the root (Figure 8.12). The surface of the crown is covered by a very hard layer of enamel. This layer is replaced by **cement** in the root, which enables the tooth to grip to its bony socket in the jaw. Below the enamel is a layer of **dentine**. Dentine is softer than enamel. Inside the dentine is a **pulp** cavity, containing nerves and blood vessels. These enter the tooth through a small hole at the base of the root.



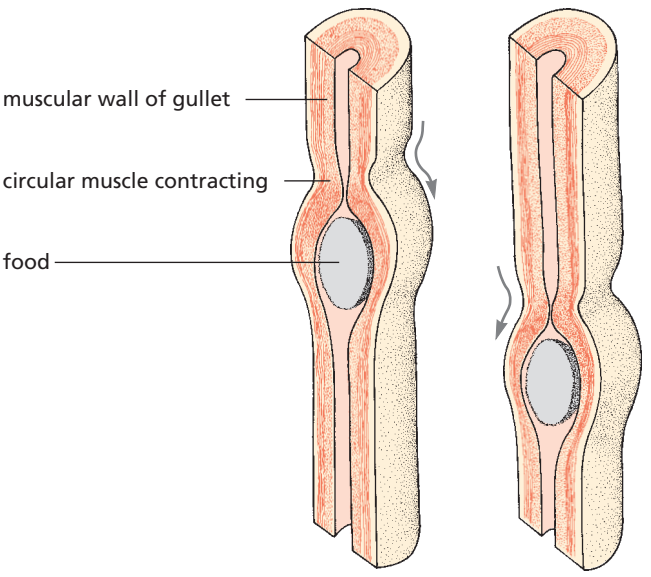
▲ **Figure 8.12** Section through a molar tooth

Peristalsis

The alimentary canal has layers of muscle in its walls (Figure 8.9). The fibres of one layer of muscles run around the tract (**circular muscle**) and the others run along its length (longitudinal muscle). When the circular muscles in one area contract, they make the alimentary canal narrow in that area.

A contraction in one area of the alimentary canal is followed by another contraction just below it so that a wave of contraction passes along the tract, pushing food in front of it. The wave of contraction, called **peristalsis**, is shown in Figure 8.13.

The process of swallowing involves peristalsis. For food to enter the **oesophagus** (gullet), it passes over the windpipe. A flap of cartilage (epiglottis) guides the food into the oesophagus. This stops food entering the windpipe, which would cause choking during swallowing. The beginning of the swallowing action is voluntary, but once the food reaches the back of the mouth, swallowing becomes a **reflex action**. The food is forced into and down the oesophagus by peristalsis. This takes about 6 seconds with quite solid food; the food is then passed into the stomach. Liquid travels more rapidly down the oesophagus.



▲ **Figure 8.13** Diagram to illustrate peristalsis

Test yourself

9 a Define the term *physical digestion*.
b State the functions of
i) incisors
ii) molars.
c State two differences between an incisor and a molar.

10 The action of teeth is one example of physical digestion.
Describe two other examples.

Chemical digestion

Digestion is mainly a chemical process and involves breaking down large molecules to small molecules. The large molecules are usually not soluble in water, but the smaller ones are. The small molecules can be absorbed through the epithelium of the alimentary canal, through the walls of the blood vessels and into the blood.

Some food can be absorbed without digestion. The glucose in fruit juice, for example, can pass through the walls of the alimentary canal and enter the blood vessels without being broken down. However, most food is solid and cannot get into blood vessels. The process of digestion dissolves solid food to make a solution.

The chemicals that dissolve the food are enzymes, described in Chapter 5. A protein can take 50 years to dissolve if just placed in water, but it is completely digested by enzymes in a few hours.

All the solid starch in foods like bread and potatoes is digested to glucose, which is soluble in water.

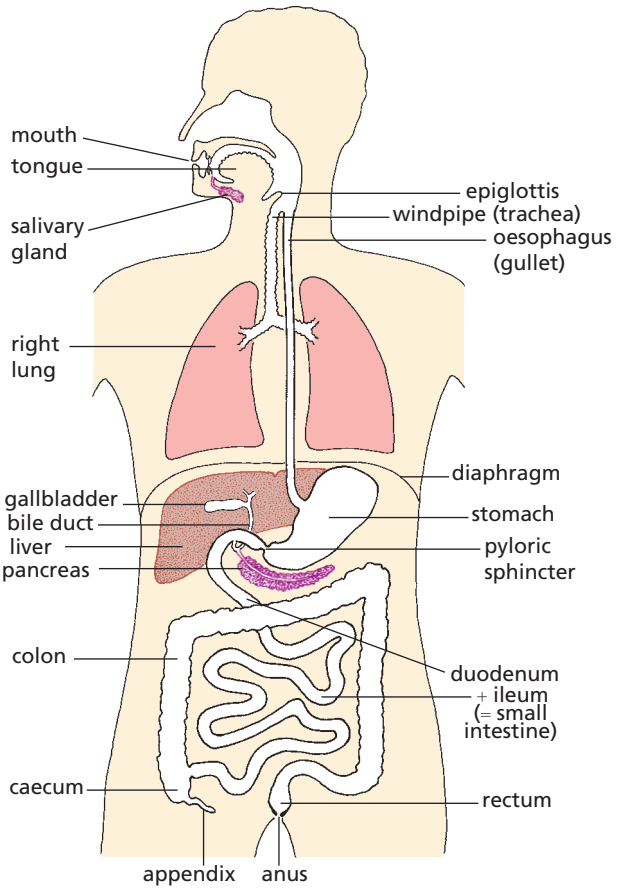
The solid proteins in meat, eggs and beans are digested to small, soluble molecules called amino acids.

Lipids are digested to soluble molecules called glycerol and fatty acids (see Chapter 4).

Five main processes linked with digestion happen in the digestive system. These are **ingestion**, digestion, absorption, **assimilation** and **egestion**. The main parts of the digestive system are shown in Figure 8.14. An outline of the functions of its main parts is given in Table 8.7.

FOCUS POINTS

★ Where are the main organs of the digestive system?



▲ **Figure 8.14** The digestive system

The mouth

The act of taking food into the mouth is called ingestion. In the mouth the food is chewed and mixed with saliva. The chewing breaks the food into pieces that can be swallowed. It also increases the surface area for the enzymes to work on later. Saliva is a digestive juice produced by the **salivary glands**, which have ducts that lead into the mouth. It helps to lubricate the food and make the small pieces stick together. Saliva contains one enzyme, **salivary amylase**, which acts on starch and begins to break it down into simple sugars.

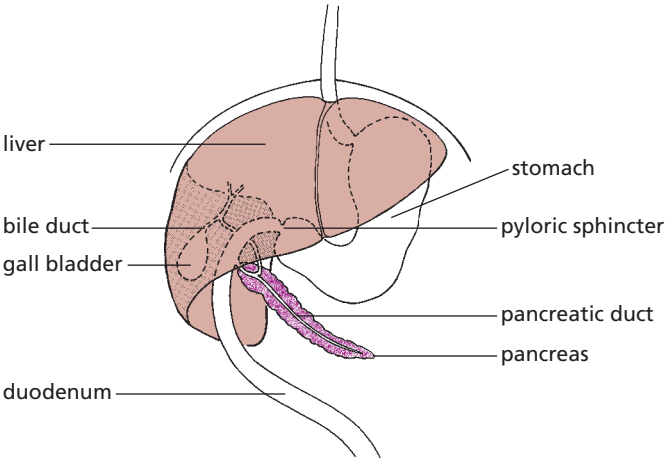
The stomach

The stomach has elastic walls, which stretch as the food collects in it. The main function of the stomach is to store the food from a meal and turn it into a liquid. An example of physical digestion is the way the muscles in the wall of the stomach work. The muscles alternately contract and relax, churning and squeezing the food in the stomach and mixing it with **gastric secretions**. The mixture is turned into a creamy liquid. This action gives the food a greater surface area so that it can be digested more efficiently. How long food remains in the stomach depends on what it contains. Water may pass through quite quickly. A meal of carbohydrate, such as porridge, may be held in the stomach for less than an hour. However, a mixed meal containing protein and fat may be in the stomach for 1 or 2 hours. Glands in the lining of the stomach produce gastric secretions containing the protease enzyme. It helps in the process of breaking down large protein molecules into small, soluble amino acids. The stomach lining also produces hydrochloric acid, which makes an acidic solution in the gastric juice. This acid gives the optimum pH for stomach protease to work in. It also kills harmful organisms in food, like bacteria taken in with the food. These can cause food poisoning if they are not killed. There is a valve at the base of the stomach. This valve stops solid pieces of food from passing through and lets the liquid products of digestion pass, a little at a time, into the **duodenum**, which is the first part of the small intestine.

Duodenum

Pancreatic juice (digestive juice from the pancreas) and bile from the liver are released into the duodenum to act on food there.

The pancreas is a digestive gland underneath the stomach (Figure 8.15). It makes several enzymes, which act on all classes of food. Protease breaks down proteins into amino acids. **Pancreatic amylase** digests starch to maltose. **Maltase** breaks down maltose into glucose. Lipase digests lipids to fatty acids and glycerol.



▲ **Figure 8.15** Relationship between stomach, liver and pancreas

All the digestible material is changed to soluble compounds, which can pass through the lining of the intestine and into the bloodstream. The final products of digestion are:

Food		Final products
starch	→	glucose (a simple sugar)
proteins	→	amino acids
lipids	→	fatty acids and glycerol

Bile

The action of bile is an example of physical digestion. **Bile** is a green, watery fluid made in the liver. It is stored in the gall bladder and is sent to the duodenum through the bile duct (Figure 8.15). It contains no enzymes but does contain bile salts. These act on lipids in a similar way to a detergent. The bile salts **emulsify** the lipids. This means they break them up into small droplets with a large surface area. The droplets are more efficiently digested by lipase.

Bile also has a function in chemical digestion. Bile is slightly alkaline as it contains sodium hydrogencarbonate and, along with pancreatic juice, has the function of neutralising the acidic mixture of food and gastric juices as it enters the duodenum. This is important because enzymes secreted into the duodenum need alkaline conditions to work at their optimum rate.

The green colour of bile is caused by bile pigments which are formed from the breakdown of haemoglobin in the liver.

Ileum and colon

The small intestine consists of the duodenum and the ileum. Nearly all the absorption of digested food and most of the water takes place in the ileum. The material passing into the large intestine consists of water with undigested matter, mainly cellulose and vegetable fibres (roughage), mucus and dead cells from the lining of the alimentary canal.

The large intestine secretes no enzymes but the bacteria in the **colon** digest part of the fibre to form fatty acids, which the colon can absorb. Bile salts are absorbed and returned to the liver in the blood. The colon also absorbs water from the undigested material. About 7 litres of digestive juices are released into the alimentary canal each day. It is important that the water from these is absorbed by the ileum and colon, or the body will become dehydrated.

Rectum and anus

The semi-solid waste is called the **faeces**. It is passed into the **rectum** by peristalsis and is passed out at intervals through the **anus**. The undigested material may spend from 12 to 24 hours in the intestine. The process of passing out the faeces is called egestion. It is important that you do not confuse egestion with excretion. The faeces is not a product of metabolism, so it is not an excretory product.

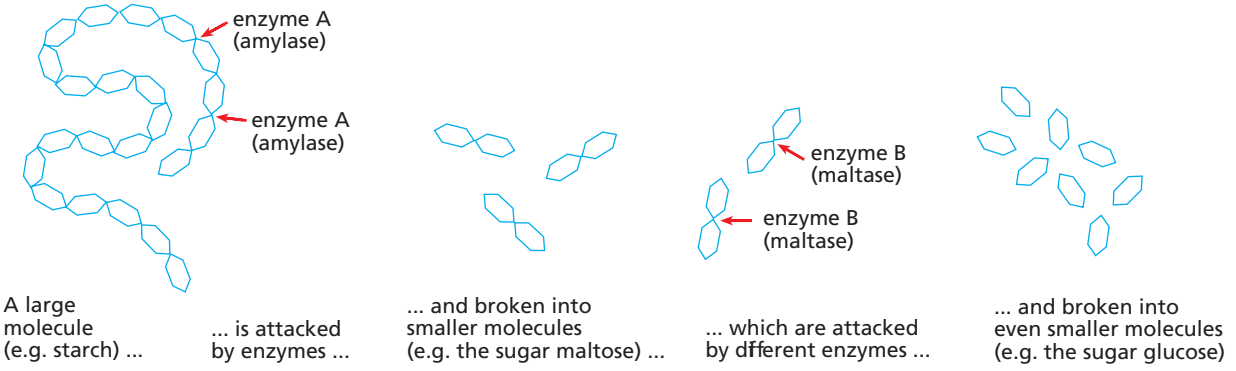
▼ **Table 8.7** Functions of the main parts of the digestive system

Region of digestive system	Function
mouth	ingestion of food; physical digestion by teeth; chemical digestion of starch by amylase; formation of a bolus for swallowing
salivary glands	produces saliva, which contains amylase for the first stage of the chemical digestion of starch in food; also, liquid to lubricate food and make small pieces stick together
oesophagus (gullet)	transfers food from the mouth to the stomach by peristalsis
stomach	produces gastric juice containing protease, for chemical digestion of protein; also, hydrochloric acid to kill bacteria; peristalsis churns food up into a liquid
duodenum	first part of the small intestine; receives pancreatic juice for chemical digestion of proteins, lipids and starch as well as neutralising the acid from the stomach; receives bile to emulsify lipids (a type of physical digestion)
ileum	second part of the small intestine; enzymes in the epithelial lining carry out chemical digestion of starch into simple reducing sugars using pancreatic amylases; proteins to amino acids by proteases; and fats and oils into fatty acids and glycerol by lipases; very long and has villi (see Figures 8.18 and 8.19) to increase surface area for absorption of digested food molecules and water
pancreas	secretes pancreatic juice into the duodenum through the pancreatic duct (see Figure 8.15 for chemical digestion of proteins, lipids and starch)
liver	makes bile containing salts to emulsify lipids (physical digestion); assimilation of digested food like glucose; **deamination** of excess amino acids (see Chapter 13), storage of glycogen (Chapter 14)
gall bladder	stores bile made in the liver, to be secreted into the duodenum through the bile duct (see Figure 8.15)
colon	first part of the large intestine; absorption of water from undigested food; absorption of bile salts to pass back to the liver
rectum	second part of the large intestine; stores faeces
anus	egestion of faeces

Digestion of starch

A starch molecule is made up of hundreds of carbon, hydrogen and oxygen atoms. Starch is digested in two places in the alimentary canal: by salivary amylase in the mouth and by pancreatic amylase in the duodenum. Amylase works best in a neutral or slightly alkaline pH and breaks down large, insoluble starch molecules into smaller, soluble maltose molecules (Figure 8.16). Maltose is a disaccharide sugar and is still too big to be absorbed through the wall of the intestine. Maltose is broken down to glucose by the enzyme maltase, which is present in the membranes of the epithelial cells of the villi.

starch ⟶ maltose ⟶ glucose



▲ **Figure 8.16** Enzymes acting on starch

Digestion of protein

Protein molecules are digested first to smaller molecules called **peptides** and then into completely soluble molecules called amino acids.

protein ⟶ peptide ⟶ amino acid

There are actually several proteases (or proteinases) which break down proteins. One protease is pepsin and is secreted in the stomach. Pepsin works best in the acid conditions in the stomach. It acts on proteins and breaks them down into soluble compounds called peptides. These are shorter chains of amino acids than proteins. Another protease is called **trypsin**. Trypsin is secreted by the pancreas in an inactive form, which is changed to an active enzyme in the duodenum. It works in a similar way to pepsin, breaking down proteins to peptides, but it works best in the alkaline conditions of the duodenum.

The small intestine itself does not appear to produce digestive enzymes. However, the epithelial cells of the villi contain enzymes in their cell membranes that complete the break-down of sugars and peptides before they pass through the cells to the bloodstream. For example, **peptidase** breaks down polypeptides and peptides into amino acids.

Digestion of lipids

The pancreas produces lipase which is secreted into the duodenum in pancreatic juice. It works best in slightly alkaline conditions (pH 8). Lipase digests lipids to fatty acids and glycerol.

Test yourself

11 Into what parts of the alimentary canal do the following pour their digestive juices?
   a the pancreas
   b the salivary glands.

12 Write down the menu for your breakfast and main meal. State the main food substances present in each item of the meal and the final digestion product of each.

13 a In which parts of the alimentary canal are the following digested?
      i) starch
      ii) protein.
   b Explain why enzymes passing from one part of the digestive system to another do not always continue to work effectively.

Absorption and assimilation

FOCUS POINTS

- ★ Where are nutrients absorbed?
- ★ Where is water absorbed?
- ★ What is assimilation?
- ★ Why are villi and microvilli important?
- ★ What is the structure of a villus?
- ★ What are the roles of capillaries and lacteals in villi?
- ★ What is the function of the hepatic portal vein?

Absorption (by diffusion, osmosis and active transport) is the movement of nutrients from the intestines into cells lining the digestive system and then into the blood. The small intestine consists of the duodenum and the ileum. Nearly all the absorption of digested food takes place in the ileum, along with most of the water. Some water is also absorbed from part of the large intestine, called the colon.

The second part of the small intestine is called the ileum. The ileum is efficient in the absorption of digested food for several reasons:

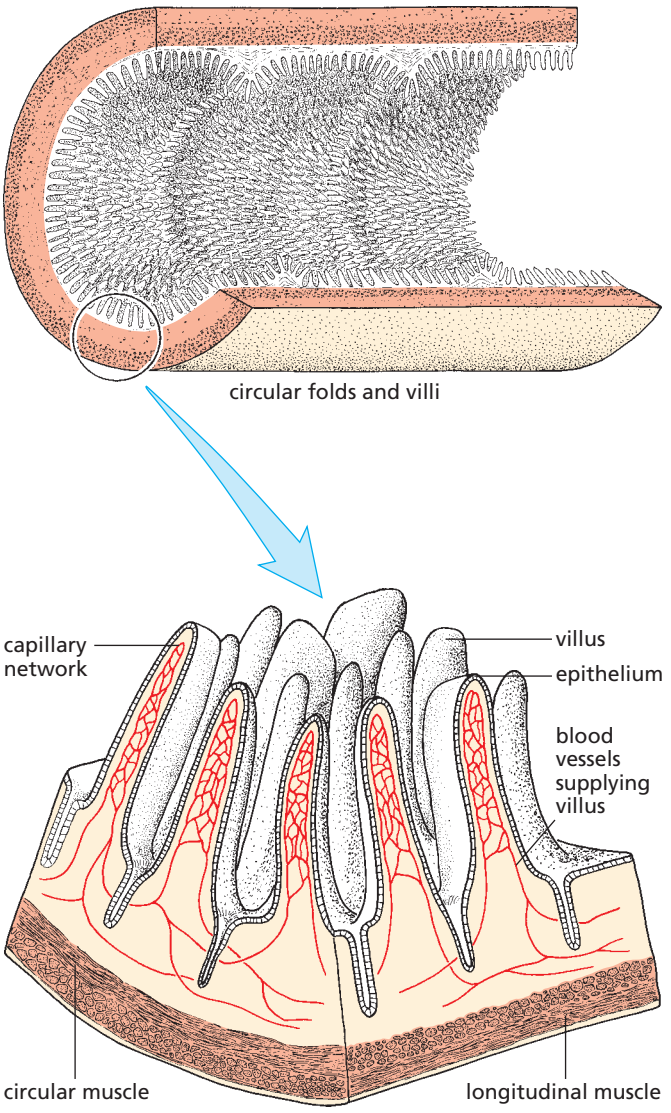
- It is quite long and provides a large surface to absorb the digested food.
- Its internal surface is increased even more by circular folds (Figure 8.19) bearing thousands of tiny projections called villi (singular = **villus**) (Figures 8.17 and 8.18). These villi are about 0.5 mm long and may be finger-like or flattened in shape.
- The lining epithelium is very thin and the fluids can pass rapidly through it. The outer membrane of each epithelial cell has microvilli, which increase ×20 the exposed surface of the cell (see Chapter 3, Figure 3.3). This makes the small intestine much more efficient in the absorption of nutrients.
- There is a dense network of blood capillaries (tiny blood vessels, see Chapter 11) in each villus (Figure 8.18).

The small molecules of digested food, for example, glucose and amino acids, pass into the epithelial cells and then through the wall of the capillaries in the villus and into the bloodstream. They are then carried away in the capillaries, which join up to form veins. These veins come together to form one large vein, the **hepatic portal vein** (see Chapter 11). This vein carries all the blood from the intestines to the liver, which may store or alter any of the digestion products. When these products are released from the liver, they enter the general blood circulation.

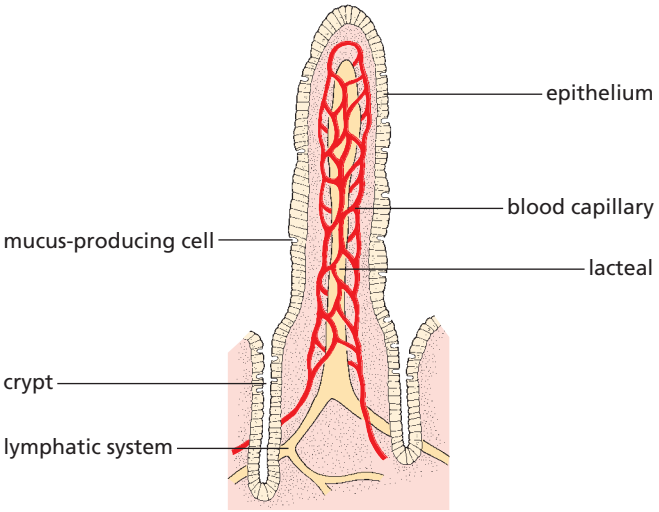
Some of the fatty acids and glycerol from the digestion of lipids enter the blood capillaries of the villi. However, a large proportion of the fatty acids and glycerol combine again to re-form lipids in the intestinal epithelium. These lipids then pass into the **lacteals** (Figure 8.18). The fluid in the lacteals flows into the lymphatic system, which forms a network all over the body and eventually empties its contents into the bloodstream.

Note: Knowledge of the lymphatic system is not required by the syllabus.

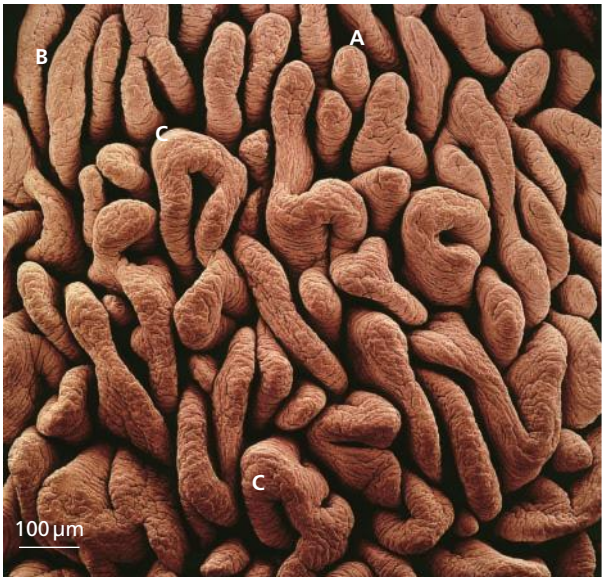
Water-soluble vitamins may diffuse into the epithelium but fat-soluble vitamins are carried in the microscopic fat droplets that enter the cells. The ions of mineral salts are probably absorbed by active transport. Calcium ions need vitamin D for their effective absorption.



▲ **Figure 8.17** The absorbing surface of the ileum



▲ **Figure 8.18** Structure of a single villus



▲ **Figure 8.19** Scanning electron micrograph of the human intestinal lining (×60). The villi are about 0.5 mm long. In the duodenum they are mostly leaf-like (C), but further towards the ileum they become narrower (B), and in the ileum they are mostly finger-like (A). This micrograph is of a region in the duodenum

Absorption of the products of digestion is not just by diffusion. Although the mechanisms for transport across the intestinal epithelium have not been fully worked out, active transport is also involved.

Even water can cross the epithelium against an osmotic gradient (Chapter 3). Amino acids, sugars and salts are, almost certainly, taken up by active transport. Glucose, for example, crosses the epithelium faster than fructose (another monosaccharide sugar) although their rates of diffusion would be about the same.

Use of digested food

The products of digestion are carried around the body in the blood. From the blood, cells absorb and use glucose, lipids and amino acids. This uptake and use of nutrients by cells is called **assimilation**.

Glucose

During respiration in the cells, glucose is oxidised to carbon dioxide and water (see 'Aerobic respiration' in Chapter 10). This reaction provides energy to drive the many chemical processes in the cells, which result in, for example, the building-up of proteins, contraction of muscles or electrical changes in nerves.

Lipids

These are built into cell membranes and other cell structures. Lipids also form an important source of energy for cell metabolism. Fatty acids produced from stored fats or taken in with the food are oxidised in the cells to carbon dioxide and water. This releases energy for processes such as muscle contraction. Lipids can provide twice as much energy as sugars.

Amino acids

These are absorbed by the cells and built up, with the aid of enzymes, into proteins. Some of the proteins will become plasma proteins in the blood (see 'Blood' in Chapter 11). Others may form structures such as cell membranes or they may become enzymes that control the chemical activity within the cell. Amino acids not needed for making cell proteins are converted by the liver into glycogen, which can then be used for energy.

Test yourself

14 For each of the classes of food listed, name the product(s) which is/are absorbed by the ileum.
- a starch
- b protein
- c fats

15 State the characteristics of the small intestine that enable it to absorb digested food efficiently.

16 Make yourself a mnemonic to help you remember the five processes happening in the digestive system (ingestion, digestion, absorption, assimilation and egestion).

Practical work

Safety

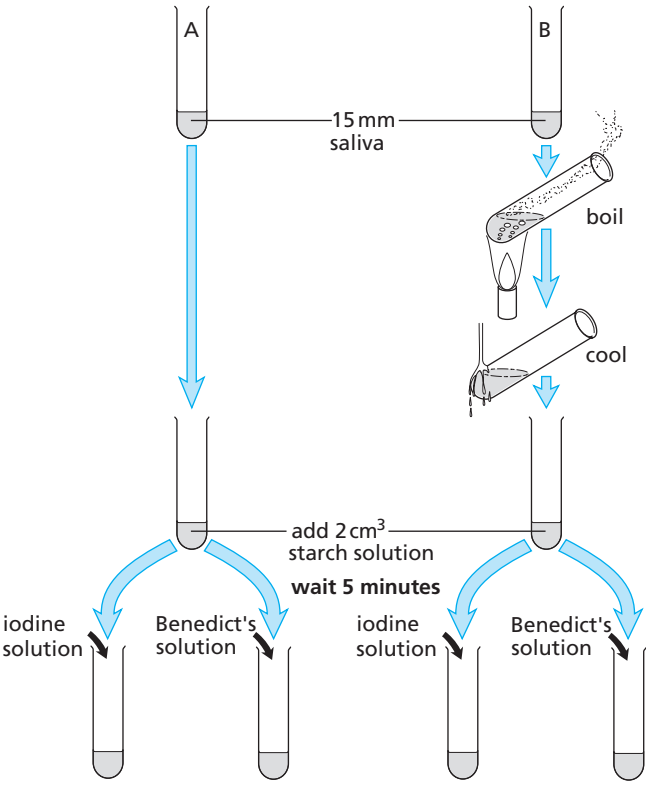
- Eye protection must be worn.
- Take care using iodine solution – it can stain skin and clothes.

Experiments on digestion

2 The action of salivary amylase on starch

- Rinse your mouth with water to remove traces of food. (**Note:** Do not do this in the laboratory and ensure you use fresh drinking water from a suitable source.)
- Collect saliva* in two test tubes, labelled A and B, to a depth of about 15 mm (see Figure 8.20). (**Note:** You should only collect and use your own saliva into a small beaker or disposable cup.)
- Heat the saliva in tube B over a small flame or in a water-bath of boiling water until it boils for about 30 seconds. Then cool the tube under the tap.
- Add about 2 cm^3 of a 2% starch solution to each tube; shake each tube and leave them for 5 minutes.
- Share the contents of tube A between two clean test tubes.
- To one of these add some iodine solution. To the other add some Benedict's solution and heat in a water-bath as described in Chapter 4.
- Test the contents of tube B in exactly the same way.

* If there is any problem using your own saliva, use a 5% solution of commercially prepared amylase instead.



▲ **Figure 8.20** Experiment to show the action of salivary amylase on starch

Results

The contents of tube A do not give a blue colour with iodine solution, showing that the starch has gone. The other half of the contents, however, gives a red or orange precipitate with Benedict's solution, showing that sugar is present.

The contents of tube B still give a blue colour with iodine solution but do not form a red precipitate on heating with Benedict's solution.

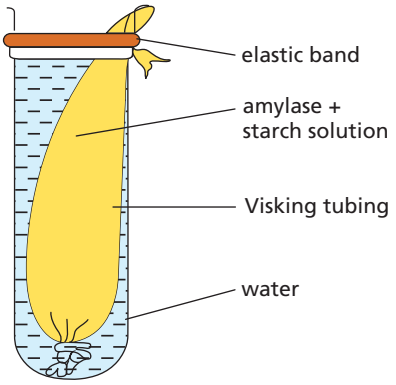
Interpretation

The results with tube A suggest that something in saliva has changed starch into sugar. The fact that the boiled saliva in tube B does not do this suggests that it was an enzyme in saliva that caused the change (see Chapter 5), because enzymes are proteins and are destroyed by boiling. If the boiled saliva had changed starch to sugar it would have ruled out the possibility of an enzyme being responsible.

This interpretation assumes that it is something in saliva that changes starch into sugar. However, the results could also support the claim that starch can turn unboiled saliva into sugar. Our knowledge of (1) the chemical composition of starch and saliva and (2) the effect of heat on enzymes, makes the first interpretation more likely.

3 Modelling the action of amylase on starch

- Collect a 15 cm length of Visking tubing that has been softened in water.
- Tie one end tightly. Using a syringe, put 2% starch solution into the Visking tubing, to about two-thirds full.
- Add 2 cm^3 of 5% amylase solution (or saliva if it is allowed).
- Pinch the top of the Visking tubing to keep it closed, then carefully mix its contents by squeezing the tubing.
- Rinse the outside of the Visking tubing thoroughly with tap water, then place it in a boiling tube, trapping the top of the tubing with an elastic band (see Figure 8.21).
- Add enough distilled water to cover the Visking tubing.
- Test a small sample of the distilled water and the contents of the Visking tubing for starch and reducing sugar, using iodine solution and Benedict's solution (see page 64 for methods).
- Place the boiling tube in a beaker of water or a water-bath at 37 °C.
- After 20 minutes, use clean teat pipettes to remove a sample of the water surrounding the Visking tubing and from inside the Visking tubing.
- Test some of each sample for starch, using iodine solution, and for reducing sugar, using Benedict's solution. Also test some of the original starch solution for reducing sugar to make sure it is not contaminated with glucose.



▲ **Figure 8.21** Experiment to model the digestion of starch

Result

At the start of the investigation the distilled water tests negative for starch (stays brown) and reducing sugar (stays turquoise). The contents of the Visking tubing are positive for starch (blue-black) but negative for reducing sugars (stays turquoise).

After 20 minutes, the contents of the Visking tubing are yellow/brown with iodine solution, but turn orange or brick red with Benedict's solution. The water sample stays yellow/brown with iodine solution, but turns orange or brick red with Benedict's solution.

Interpretation

The amylase digests the starch in the Visking tubing, producing reducing sugar. The complete digestion of starch results in a negative colour change with iodine solution. The presence of reducing sugar (maltose or glucose) causes the Benedict's solution to turn orange or brick red. The reducing sugar molecules can diffuse through the Visking tubing into the surrounding water, so the water gives a positive result with Benedict's solution.

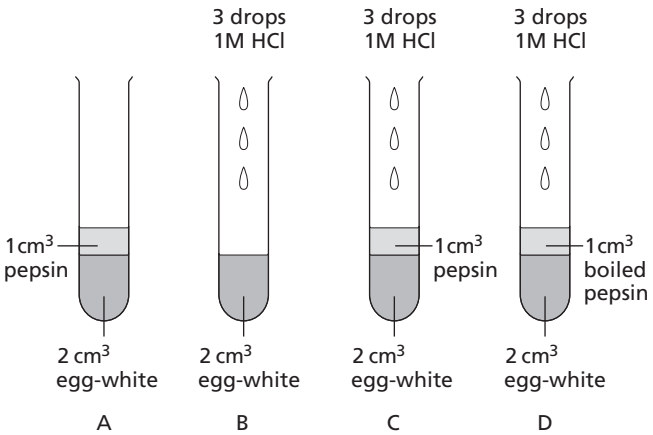
Starch is a large molecule, so it cannot diffuse through the tubing: the water gives a negative result with iodine solution.

This model can be used to represent digestion in the gut. The starch solution and amylase are the contents of the mouth or duodenum. The Visking tubing represents the duodenum wall and the distilled water represents the bloodstream, into which the products of digestion are absorbed.

4 The action of pepsin on egg white protein

Prepare a cloudy suspension of egg white by stirring the white of one egg into 500 cm^3 tap water, heating it to boiling point in a water-bath. Allow it to cool before filtering it through glass wool to remove the larger particles.

- Label four test tubes A, B, C and D and place 2 cm^3 egg white suspension in each of them. Then add pepsin solution and/or dilute (1M) hydrochloric acid (HCl) to the tubes, as shown in Figure 8.22.



▲ **Figure 8.22** Experiment to show the action of pepsin on egg white

A egg white suspension + 1 cm^3 pepsin solution (1%)
B egg white suspension + 3 drops dilute HCl
C egg white suspension + 1 cm^3 pepsin + 3 drops HCl
D egg white suspension + 1 cm^3 boiled pepsin + 3 drops HCl

- Place all four tubes in a beaker of warm water at 35 °C for 10–15 minutes.

Result

The contents of tube C go clear. The rest stay cloudy.

Interpretation

The change from a cloudy suspension to a clear solution shows that the solid particles of egg protein have been digested to soluble products. The failure of the other three tubes to give clear solutions shows that:

- pepsin will only work in acid solutions
- it is the pepsin and not the hydrochloric acid that does the digestion
- pepsin is an enzyme, because its activity is destroyed by boiling.

For experiments investigating the effect of temperature and pH on enzyme action see Chapter 5.

Practical work questions

4 In experiment 3, explain why some reducing sugar remains inside the Visking tubing.
5 In experiment 4, explain why the change from cloudy to clear suggests that digestion has occurred.
6 Suggest how you would modify experiment 4 if you wanted to find the optimum temperature for the action of pepsin on egg white.
7 Experiment 4 is really two experiments combined because there are two variables.
a Identify the variables.
b State which of the tubes could be the control.

Revision checklist

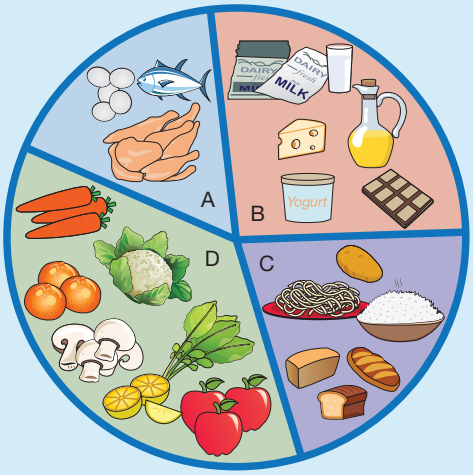
After studying Chapter 8 you should know and understand the following:

- ✔ A balanced diet must contain proteins, carbohydrates, lipids, mineral salts, vitamins, fibre and water in the correct proportions.
- ✔ Dietary needs are affected by the age, gender and activity of humans.
- ✔ Lipids, carbohydrates and proteins provide energy.
- ✔ Proteins provide amino acids for the growth and replacement of tissues.
- ✔ The uses of mineral ions, fibre and vitamins in the body.
- ✔ Shortage of vitamin C causes scurvy; shortage of vitamin D causes rickets.
- ✔ The main regions of the digestive system and their functions.
- ✔ Digestion takes place to break down large, insoluble food molecules into small, soluble molecules so that they can be absorbed.
- ✔ Physical digestion breaks down food into smaller pieces, without any chemical change of the food molecules. This process involves teeth and muscles of the stomach.
- ✔ Types of human teeth, their structure and functions.
- ✔ Bile emulsifies fats and oil, increasing their surface area for the action of enzymes in chemical digestion.
- ✔ Chemical digestion is the process that changes large, insoluble food molecules into small, soluble molecules, so that they can be absorbed.
- ✔ The changes are brought about by digestive enzymes.
- ✔ Functions of amylase, protease and lipase, their substrates and products.
- ✔ Sites of digestion.
- ✔ Hydrochloric acid in the stomach kills harmful bacteria and provides an optimum pH for enzyme activity.
- ✔ Digestion of starch and protein.
- ✔ Bile is alkaline and neutralises the acidic food mixture when it enters the duodenum from the stomach so the enzymes will be able to act.
- ✔ Nutrients are absorbed in the small intestine.
- ✔ Most water is absorbed in the small intestine, some in the colon.
- ✔ Villi and microvilli greatly increase the absorbing surface of the small intestine.
- ✔ In the villi, glucose and amino acids pass into the blood in capillaries, and most fatty acids and glycerol pass into the fluid in the lacteals.
- ✔ The hepatic portal vein as the route taken to the liver by most of the molecules and ions absorbed from the ileum.

Exam-style questions

1 a Define the term *balanced diet*. [2]
Some examples of the food that would give a balanced diet are shown in the diagram below.

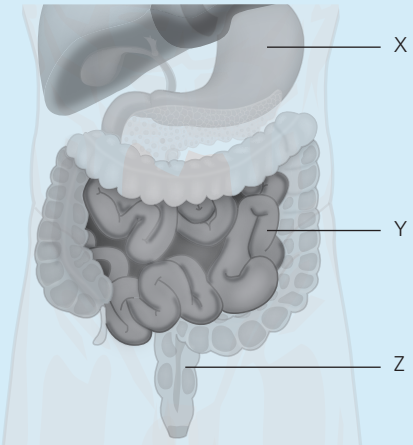
b Study the picture and state what class of food or item of diet is mainly present in each of the segments A, B, C and D. [4]



c Explain why it is important to have leafy vegetables, for example, cabbage and lettuce in the diet. [2]

2 State which tissues of the body need
a calcium
b glucose
c iron
d protein. [4]

3 The diagram shows a view of the digestive system in a person's abdomen.



a Identify parts X, Y and Z and state one function for each part. [6]

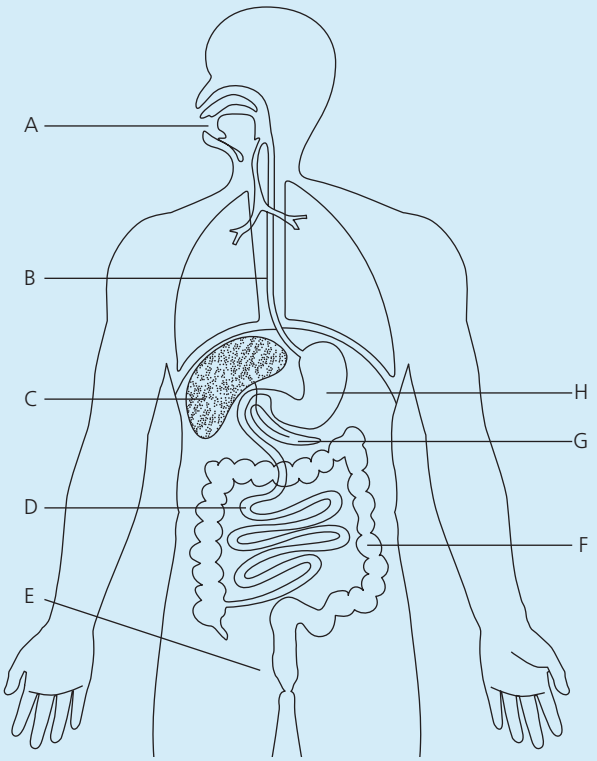
b i) State the type of enzyme secreted by organ X. [1]

ii) Describe the conditions in organ X that make digestion efficient. [2]

4 a State the process by which the *majority* of the sugar is absorbed through the ileum wall into the bloodstream. [1]

b What is needed to achieve this process? [1]

5 The diagram shows the digestive system of a human.



Identify which labels show the site(s) of
a physical digestion [2]
b egestion [1]
c absorption of water [1]
d acid pH [1]
e starch digestion [1]
f production of an alkaline solution. [1]

6 The main processes in the digestive system are shown below. Copy the words below and draw a straight line to match each process to its definition. [5]

process	definition
absorption	the taking of substances, e.g. food and drink, into the body
assimilation	the breakdown of food
digestion	the movement of nutrients from the intestines into the blood
egestion	the uptake and use of nutrients by cells
ingestion	the removal of undigested food from the body as faeces

7 Outline what happens to a protein molecule in food, from when it is swallowed to when its products are built up into the cytoplasm of a muscle cell. [10]

9 Human gas exchange

Focus

Cells cannot function without oxygen and need to get rid of the potentially poisonous gas, carbon dioxide. So, how does the body obtain the oxygen and remove the carbon dioxide? What happens when we exercise and need more oxygen than normal? This chapter explores gas exchange and how the breathing system adjusts to changing demands.

FOCUS POINTS

- ★ What are the features of gas exchange surfaces in humans?
- ★ Where in the body are the parts of the gas exchange system?
- ★ How do the ribs, internal and external intercostal muscles and diaphragm ventilate the lungs?
- ★ Why is the composition of inspired air different to expired air?
- ★ Why does the rate and depth of breathing increase during and after physical activity?
- ★ How do goblet cells, mucus and ciliated cells protect the gas exchange system from pathogens and particles?

Gas exchange in humans

All the processes carried out by the body, like movement, growth and reproduction, require energy. In animals, this energy can only be obtained from the food they eat. Before the energy can be used by the cells of the body, it must be set free from the chemicals of the food by a process called respiration (see Chapter 10). Aerobic respiration needs a supply of oxygen and produces carbon dioxide as a waste product. So, all cells must be supplied with oxygen and must be able to get rid of carbon dioxide.

In humans and other mammals, the oxygen is gained from the air by means of the lungs. In the lungs, the oxygen dissolves in the blood and is carried to the tissues by the circulatory system (Chapter 11).

Features of respiratory surfaces

The exchange of oxygen and carbon dioxide across a respiratory surface, as in the lungs, depends on the diffusion of these two gases. Diffusion occurs more rapidly if

- there is a large surface area exposed to the gas
- the distance across which diffusion takes place is small
- there is a good blood supply
- there is a big difference in the concentrations of the gas at two points achieved by ventilation.

Large surface area

The presence of millions of alveoli in the lungs provides a very large surface for gaseous exchange.

Thin epithelium

There is only a two-cell layer, at the most, separating the air in the alveoli from the blood in the capillaries (Figure 9.4). One layer is the alveolus wall; the other is the capillary wall. So, the distance for diffusion is very short.

Good blood supply

The alveoli are surrounded by networks of blood capillaries. The blood in these capillaries removes oxygen all the time, keeping the oxygen concentration low. In this way, a steep diffusion gradient is maintained. This helps the rapid diffusion of oxygen from the air passages to the alveolar lining.

Carbon dioxide from the blood is delivered continuously into the alveoli. It is removed from the air passages by ventilation, maintaining a diffusion gradient in the same way. This encourages the diffusion of carbon dioxide from the alveolar lining into the **bronchioles**.

Ventilation

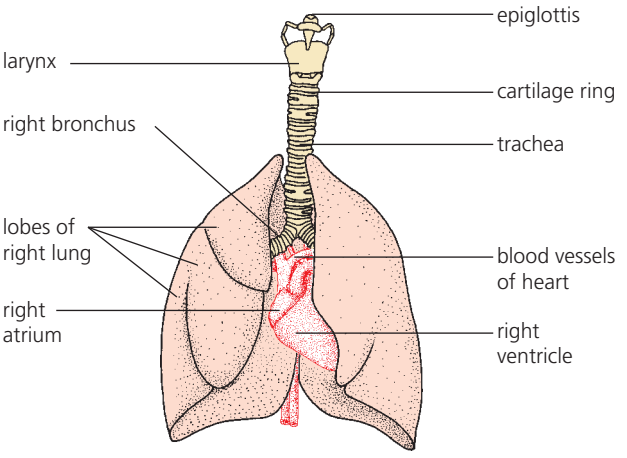
Ventilation of the lungs helps to maintain a steep diffusion gradient (see 'Diffusion' in Chapter 3) between the air at the end of the air passages and the alveolar air. The concentration of the oxygen in the air at the end of the air passages is high because the air is constantly replaced by the breathing actions.

The respiratory surfaces of land-dwelling mammals are moist. Oxygen must dissolve in the thin film of moisture before passing across the epithelium.

Lung structure

The lungs are found in the thorax (chest region) (see Figure 8.14). They have a spongy texture and can be expanded and compressed by movements of the thorax so that air is sucked in and blown out. The back of the mouth connects to the **larynx**, which joins onto the windpipe or **trachea** (Figure 9.1). The trachea divides into two smaller tubes, called **bronchi** (singular = bronchus), which enter the lungs and divide into even smaller branches. When these branches are only about 0.2 mm in diameter they are called bronchioles (Figure 9.3(a)). These fine branches end in a mass of little, thin-walled, pocket-like air sacs called alveoli (Figures 9.3(b), (c) and 9.4).

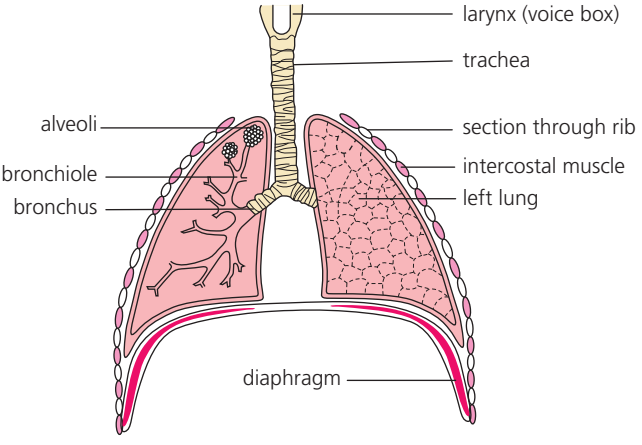
A flap of tissue (epiglottis) and other structures at the top of the trachea stop food and drink from entering the air passages when we swallow.



▲ **Figure 9.1** Diagram of lungs, showing position of heart

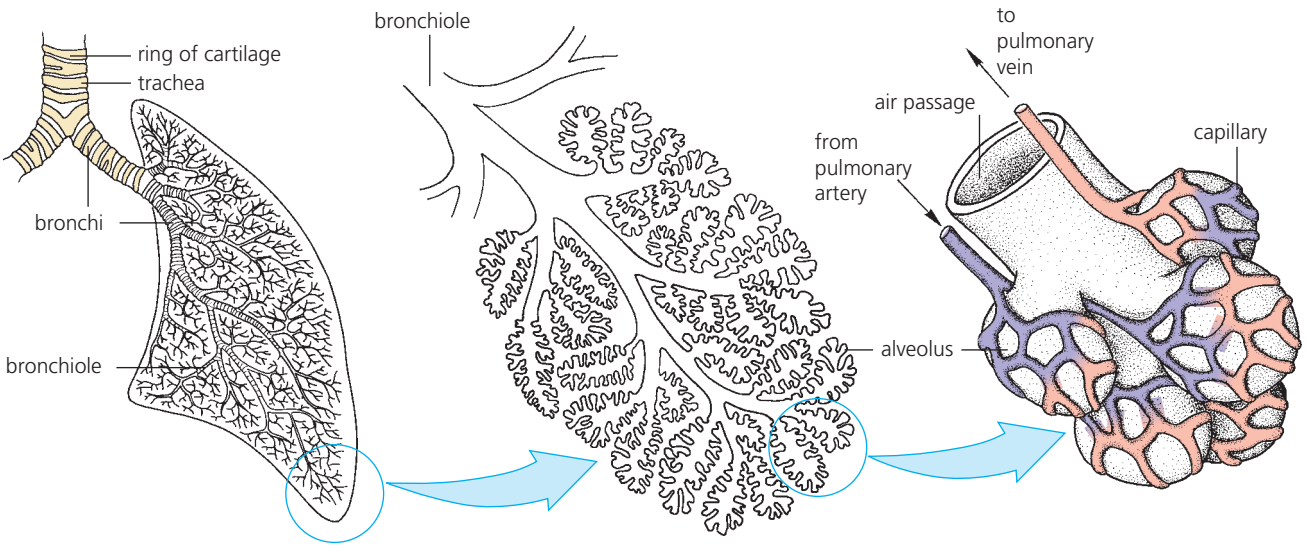
Figure 9.2 shows a section through the thorax. The ribs, shown in cross-section, form a cage, which has two main functions:

- To protect the lungs and heart.
- To move to ventilate the lungs.



▲ **Figure 9.2** Section through the thorax

The alveoli have thin elastic walls made of a single-cell layer or **epithelium**. Over the epithelium is a dense network of capillaries (Figure 9.3(c)) supplied with **deoxygenated** blood (see 'Blood' in Chapter 11). This deoxygenated blood is pumped from the right **ventricle** through the **pulmonary artery** (see Figure 11.17). In humans, there are about 350 million alveoli, with a total absorbing surface of about 90 m^2. This large absorbing surface makes it possible to take in oxygen and give out carbon dioxide at a rate to meet the body's needs.

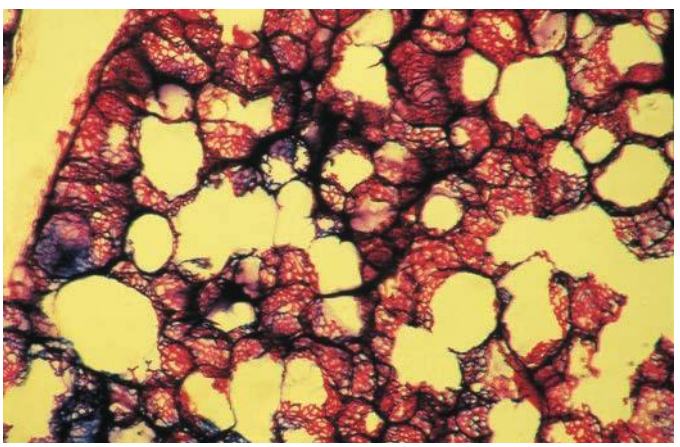


(a) air passages in the lungs

(b) the air passages end in tiny pockets (alveoli)

(c) blood supply of the alveoli

▲ **Figure 9.3** Lung structure



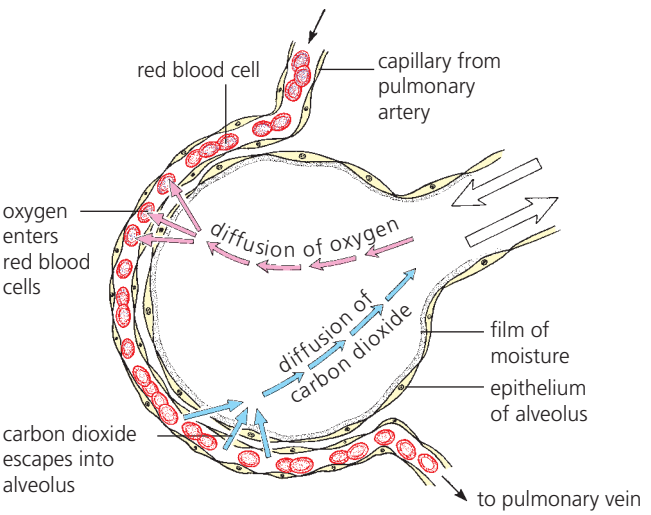
▲ **Figure 9.4** Small piece of lung tissue (×40). The capillaries have been injected with red and blue dye. The networks surrounding the alveoli can be seen

Test yourself

1. Place the following structures in the order in which air will reach them when breathing in: bronchus, trachea, nasal cavity, alveolus.
2. There are 350 million alveoli in the human lungs and the bronchioles are 0.2 mm in diameter. Convert these figures to standard form.
3. One of the alveoli in Figure 9.4 is 10 mm wide. The magnification of the photomicrograph is ×40. Calculate the actual diameter of the alveolus. Give your answer in standard form in micrometres.
4. Describe how the lungs are adapted to make the diffusion of gases efficient.

Gaseous exchange

Ventilation means the movement of air into and out of the lungs. Gaseous exchange is the exchange of oxygen and carbon dioxide, which takes place between the air and the blood vessels in the lungs (Figure 9.5).



▲ **Figure 9.5** Gaseous exchange in the alveolus

The capillaries carrying **oxygenated** blood from the alveoli join up to form the **pulmonary vein** (see Figure 11.17). This vein returns blood to the left **atrium** of the heart. From here the blood enters the left ventricle and is pumped all around the body, so supplying the tissues with oxygen.

Table 9.1 shows changes in the composition of air as it is breathed in and out.

▼ **Table 9.1** Changes in the composition of breathed air

	Inhaled/%	Exhaled/%
oxygen	21.00	16.00
carbon dioxide	0.04	4.00
water vapour	variable	saturated

Differences in composition of inspired and expired air

Air in the atmosphere (which is breathed in) contains about 21% oxygen (see Table 9.1). Some of this is absorbed into the bloodstream when it enters the alveoli, resulting in a reduction of oxygen in exhaled air to 16% (the process of gaseous exchange in the alveoli does not remove all the oxygen from the air). Gas exchange depends on diffusion to transfer the oxygen into red blood cells. The air breathed in mixes with air that has not all been breathed out from the previous breath, so the process of gas exchange is not very efficient.

The remaining 79% of the air is mainly nitrogen and does not change much during breathing.

Inspired air contains 0.04% carbon dioxide. Cells of the body produce carbon dioxide as a waste product during aerobic respiration (see 'Aerobic respiration' in Chapter 10). The bloodstream carries carbon dioxide to the lungs for excretion. It diffuses across the walls of the alveoli to be expired. The percentage breathed out is 4%, 100 times greater than the percentage breathed in.

The oxygen dissolves in a film of moisture that lines the alveoli. Some of this moisture evaporates into the alveoli and saturates the air with water vapour. So, the air you breathe out always contains a lot more water vapour than the air you breathe in. You can show the presence of water vapour in expired air easily by breathing onto a cold mirror: condensation quickly builds up on the glass surface. The exhaled air is warmer as well, so in cold and mild climates you lose heat to the atmosphere by breathing.

Sometimes the word respiration is used in connection with breathing. The lungs, trachea and bronchi are called the respiratory system; a person's rate of breathing may be called his or her respiration rate. Be careful not to be confused with the biological meaning of respiration, which is the release of energy in cells (Chapter 10). This chemical process is sometimes called tissue respiration or internal respiration to distinguish it from breathing.

Lung capacity and breathing rate

The total volume of the lungs when fully inflated is about 5 litres in an adult. However, in quiet breathing, when asleep or at rest, you normally exchange only about 500 cm^3. During exercise you can take in and breathe out an extra 3 litres. There is a residual volume of 1.5 litres, which cannot be expelled no matter how hard you breathe out.

At rest, you normally inspire and expire about 12 times per minute. During exercise, the breathing rate may rise to over 20 breaths per minute, and the depth of breathing also increases.

Breathing rate and exercise

The increased rate and depth of breathing during exercise allows more oxygen to dissolve in the blood and supply the active muscles. The extra carbon dioxide that the muscles put into the blood is detected by the brain. It instructs the **intercostal muscles** and diaphragm muscles to contract and relax more rapidly, increasing the breathing rate. Carbon dioxide will be removed by the faster, deeper breathing.

Test yourself

5 Explain why carbon dioxide diffuses out of the blood into the alveolus.
6 State two ways in which expired air is different from inspired air.
7 Make a mnemonic to remember the order of structures in the breathing system, starting at the mouth.

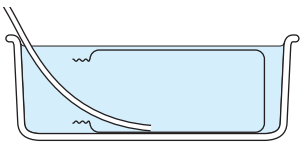
Practical work

Safety

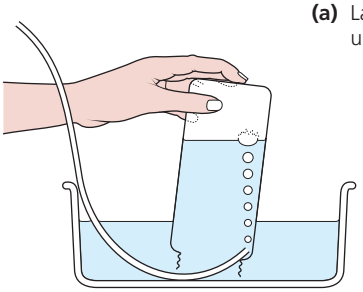
- Eye protection must be worn.

1 Oxygen in expired air

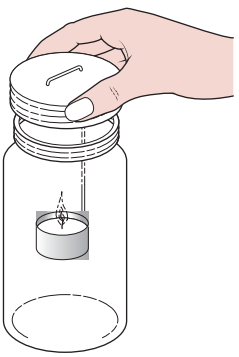
- Place a large screw-top jar on its side in a bowl of water (Figure 9.6(a)).
- Put a rubber tube in the mouth of the jar and then turn the jar upside-down. Make sure the water and rubber tube stay in the jar.
- Start breathing out. When you feel your lungs must be about half empty, breathe the last part of the air down the rubber tubing. The air will collect in the upturned jar and fill it (Figure 9.6(b)).
- Keep the jar under water while you put the screw top back on. Then, remove the jar from the bowl and place it the right way up on the bench.



(a) Lay the jar on its side under the water.



(b) Breathe out through the rubber tube and trap the air in the jar.



(c) Lower the burning candle into the jar until the lid is resting on the rim.

▲ **Figure 9.6** Experiment to test expired air for oxygen

- Light the candle on the special wire holder (Figure 9.6(c)) and remove the lid of the jar. Quickly lower the burning candle into the jar and count the number of seconds the candle stays alight.
- Now take a fresh jar, with ordinary air, and see how long the candle stays alight in this.

Results

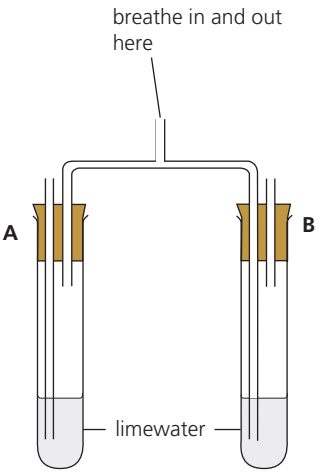
The candle will burn for about 15–20 seconds in a large jar of ordinary air. In expired air it will go out in about 5 seconds.

Interpretation

Burning needs oxygen. When the oxygen is used up, the flame goes out. It looks as if expired air contains much less oxygen than atmospheric air.

2 Carbon dioxide in expired air

- Prepare two large boiling tubes, A and B, as shown in Figure 9.7, with each containing a small amount of clear limewater.
- Put the mouthpiece in your mouth and breathe in and out ***gently*** through it for about 15 seconds. Notice which tube is bubbling when you breathe out and which one bubbles when you breathe in.



▲ **Figure 9.7** Experiment to compare the carbon dioxide content of inspired and expired air

If there is no difference in the appearance of the limewater in the two tubes after 15 seconds, continue breathing through them for another 15 seconds.

Results

The limewater in tube B goes milky. The limewater in tube A stays clear.

Interpretation

Carbon dioxide turns limewater milky. Expired air passes through tube B. Inspired air passes through tube A. So, expired air must contain more carbon dioxide than inspired air.

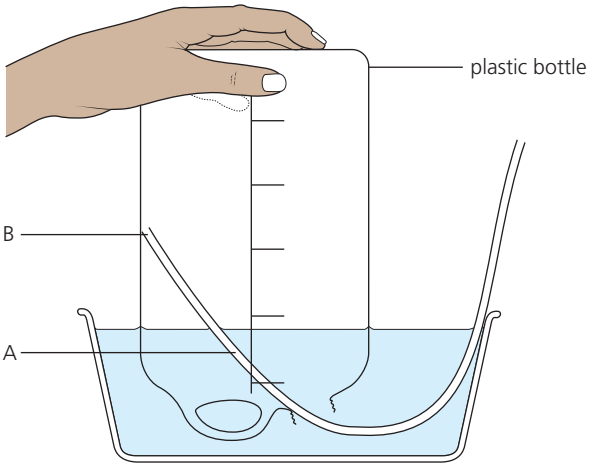
Note 1: If the breathing process is carried out for too long, the limewater that had turned milky will return to being colourless. This is because the calcium carbonate formed (milky precipitate) reacts in water with carbon dioxide to form calcium hydrogencarbonate, which is soluble and colourless.

Note 2: Hydrogencarbonate indicator is an alternative to limewater. It changes from red to yellow when carbon dioxide is bubbled through it.

Note 3: Make sure the boiling tubes are really clean because if they are not the limewater (or hydrogencarbonate indicator) will change colour before you start the experiment.

3 Volume of air in the lungs

- Calibrate a large (5 litre) plastic bottle by filling it with water, half a litre at a time, and marking the water levels on the outside.
- Fill the bottle with water and put on the stopper.
- Put about 50 mm depth of water in a large plastic bowl.
- Hold the bottle upside-down with its neck under water and remove the screw top. Some of the water will run out but this does not matter.
- Push a rubber tube into the mouth of the bottle to position A, shown on the diagram (Figure 9.8).
- Take a deep breath and then expire as much air as possible down the tubing into the bottle. The final water level inside the bottle will tell you how much air you can exchange in one deep breath.
- Now push the rubber tubing further into the bottle, to position B (Figure 9.8), and blow out any water left in the tube.
- Support the bottle with your hand and breathe gently in and out through the tube, keeping the water level inside and outside the bottle the same. This will give you an idea of how much air you exchange when breathing normally.



▲ **Figure 9.8** Experiment to measure the volume of air expired from the lungs. (A) shows the position of the tube when measuring the maximum usable lung volume. (B) is the position for measuring the volume exchanged in gentle breathing

Results

The first reading can be between 2.5 and 5.0 litres. The second reading is about 500cm^3.

Interpretation

The first reading represents your vital capacity. The second reading is your tidal volume.

4 Investigating the effect of exercise on carbon dioxide production

- Half fill two clean boiling tubes with limewater.
- Place a drinking straw in one of the boiling tubes and gently blow into it with normal, relaxed breaths.
- Count how many breaths are needed to turn the limewater milky.
- Now exercise for 1 to 2 minutes, for example, running on the spot.
- Place a drinking straw in the second boiling tube, blowing into it as before.
- Count the number of breaths needed to turn the limewater milky.

Results

The number of breaths needed after exercise will be less than before exercise.

Interpretation

Cells in the body are constantly respiring, even when we are not doing physical work. They produce carbon dioxide, which is expired by the lungs. The carbon dioxide turns limewater milky. During exercise, cells (especially in the skeletal muscles) respire more rapidly, so producing more carbon dioxide. This turns the limewater milky more rapidly.

Going further

Practical work

5 Investigating the effect of exercise on rate and depth of breathing

An instrument called a spirometer is used as a piece of medical equipment for measuring and recording the volume of air inspired and expired by the lungs of a patient. In a medical setting, the results can be studied to identify abnormal patterns of ventilation. This investigation uses a spirometer. It may be one as shown in Figure 9.9, or a digital version connected to a computer. A traditional spirometer has a hinged chamber, which rises and falls as a person breathes through the mouthpiece. The chamber is filled with medical oxygen from a cylinder. There is a filter containing soda lime, which removes any carbon dioxide in the user's breath so that it is not re-breathed. The hinged chamber has a pen attached (shown in red in Figure 9.9), which rests against the paper-covered drum of a kymograph. This can be set to revolve at a fixed rate so that the trace produced by the user moves across the paper.

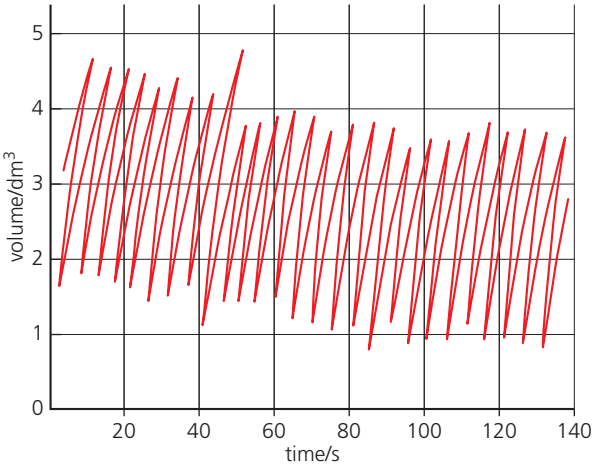
▲ **Figure 9.9** A spirometer. This instrument measures the volume of air breathed in and out of the lungs and can be used to measure oxygen consumption

- A volunteer is asked to breathe in and out through the mouthpiece and the kymograph is set to rotate slowly. This will generate a trace, which will provide information about the volunteer's tidal volume and breathing rate (each peak on the trace represents one breath and the depth between a peak and trough can be used to calculate the tidal volume).
  Note: The volunteer should not be able to see the trace being produced, as this can affect his or her breathing pattern.
- Next, the volunteer is asked to take a deep breath with the mouthpiece removed, then breathe out through the mouthpiece for one long continuous breath. The depth between the peak and trough produced can be used to calculate the vital capacity.
- Finally, the volunteer is asked to insert the mouthpiece then run on the spot or pedal an exercise bicycle while breathing through the spirometer. The trace produced (Figure 9.10) can be used to compare the breathing rate and depth during exercise with that at rest. A study of the trace would also show a drop in the trace with time. This can be used to calculate the volume of oxygen used over time.

Results

Tidal volume is about 500 cm^3, but can appear higher if the person is nervous or influenced by the trace being made.

Vital capacity can be between 2.5 and 5.0 litres, depending on the sex, physical size and fitness of the person.



▲ **Figure 9.10** Spirometer trace taken during exercise

The breathing rate at rest is around 12 breaths per minute. During exercise this increases and may reach 20 or more breaths per minute.

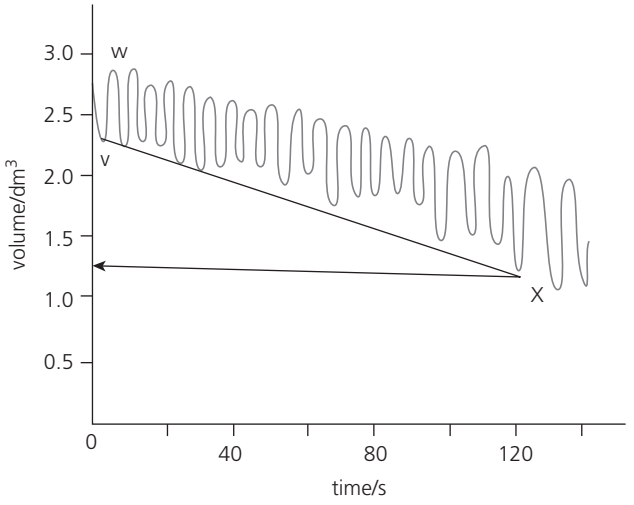
Note: This experiment makes use of medical oxygen. This has a high purity and is toxic if inhaled for too long. If the volunteer starts to feel dizzy while using the spirometer, he or she should remove the mouthpiece immediately and rest.

Practical work questions

1. (Experiment 1) Explain why the candle does not go out immediately when it is put into the expired air.
2. (Experiment 2) Explain how you know which tube has been testing for inspired air and which has been testing for expired air.
3. (Experiment 3) State by how much the volume of a forced exhalation differs from the volume breathed out during relaxed breathing.
4. (Experiment 4) Explain why the limewater turned milky even during normal, relaxed breathing.

Worked example

The diagram shows a spirometer trace.



The volume of air inspired or expired in one breath (the depth of breathing) can be found by subtracting the volume at one peak on the trace (e.g. point W) from the volume at the next trough (e.g. point V). In this case W = 2.8 dm^3 and V = 2.3 dm^3.

2.8 – 2.3 = 0.5 dm^3.

If there is variation in peaks and troughs, a number of volumes can be calculated and then the mean volume can be found.

The number of breaths per minute (the rate of breathing) can be found by adding up the number of peaks (or troughs) in a fixed time, then dividing the total by the number of minutes. In the example, you can count the number of troughs between V and X. There are 20 troughs in 2 minutes.

20 ÷ 2 = 10 breaths per minute.

The volume of oxygen used in a fixed period of time can be found by subtracting the volume at a peak or trough at the start of the time period from the volume of a peak or trough at the end of the time period. We can use points V (2.3 dm^3) and X (1.25 dm^3).

2.3 – 1.25 = 1.05 dm^3.

This volume of oxygen used is over 2 minutes.

1.05 ÷ 2 = 0.525 litres per minute.

Tasks

1. Study Figure 9.10, which shows a spirometer trace.
   - a State how long the volunteer was breathing through the spirometer.
   - b Describe how the volunteer's breathing rate can be calculated using the spirometer trace.
   - c After 10 seconds of exercise, the volume of oxygen in the spirometer was 4.7 dm^3. At 137 seconds, the volume was 3.8 dm^3.
     Calculate the rate of oxygen consumed by the volunteer in litres per minute.

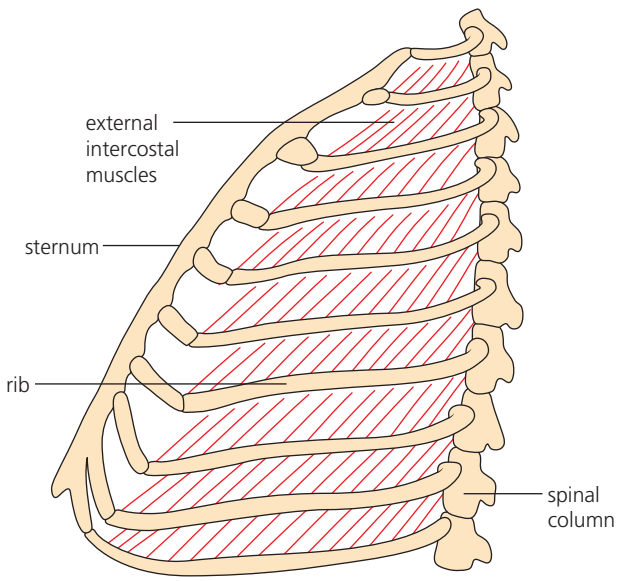
Ventilation of the lungs

The movement of air into and out of the lungs is called ventilation. It renews the oxygen supply in the lungs and removes the remaining carbon dioxide. Horseshoe-shaped hoops of cartilage are present in the trachea and bronchi to stop them collapsing when we breathe in. The lungs contain no muscle fibres and are made to expand and contract by movements of the ribs and diaphragm.

The diaphragm is a sheet of muscle tissue that separates the thorax from the abdomen (see Figure 9.2). When relaxed, it is domed slightly upwards. The ribs are moved by the intercostal muscles. The **external intercostals** (Figure 9.11) contract to pull the ribs upwards and outwards. The **internal intercostals** contract to pull them downwards and inwards. Figure 9.12 shows the contraction of the external intercostales making the ribs move upwards.

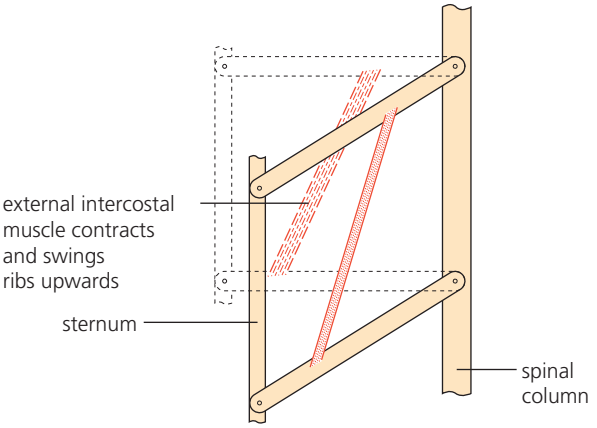
Inspiration

1. The diaphragm muscles contract and pull the diaphragm down (Figure 9.14(a)).
2. The internal intercostal muscles relax while the external intercostal muscles contract and pull the ribcage upwards and outwards (Figure 9.15(a)).



▲ **Figure 9.11** Ribcage seen from left side, showing external intercostal muscles

These two movements make the volume in the thorax bigger, so forcing the lungs to expand. The reduction in air pressure in the lungs results in air being pulled in through the nose and trachea. This movement of air into the lungs is known as ventilation.

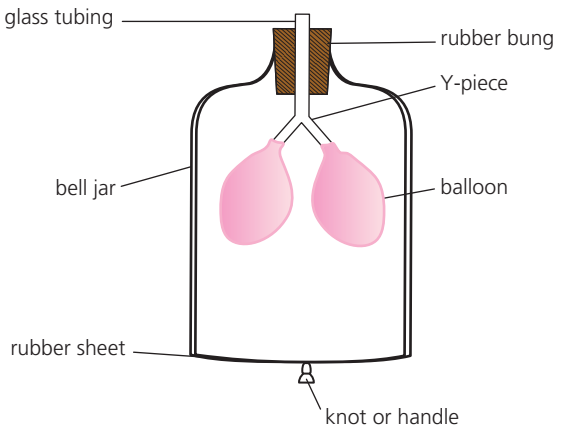


▲ **Figure 9.12** Model to show action of intercostal muscles

Expiration

1. The diaphragm muscles relax, allowing the diaphragm to return to its domed shape (Figure 9.14(b)).
2. The external intercostal muscles relax while the internal intercostal muscles contract, pulling the ribs downwards to cause a forced expiration (Figure 9.15(b)).

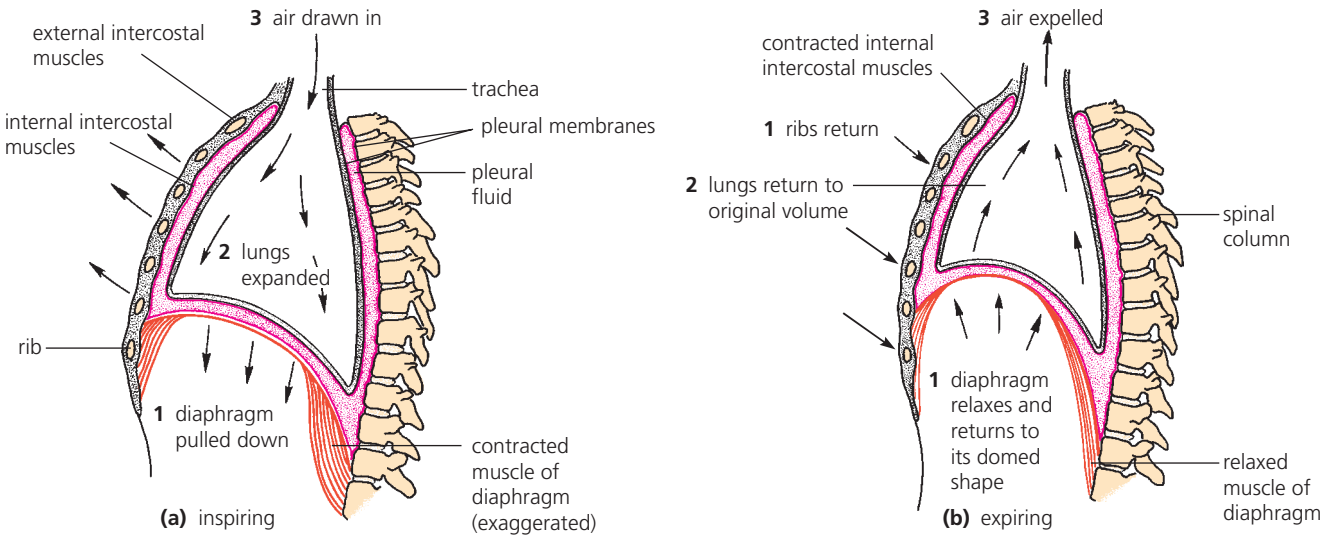
The lungs are elastic and shrink back to their relaxed volume, increasing the air pressure inside them. This results in air being forced out again. A piece of apparatus called the bell-jar model (Figure 9.13) can be used to show the way in which movement of the diaphragm results in inspiration and expiration. The balloons start off deflated. When the handle attached to the rubber sheet is pulled down, the balloons inflate. If the handle is released, the balloons deflate again.



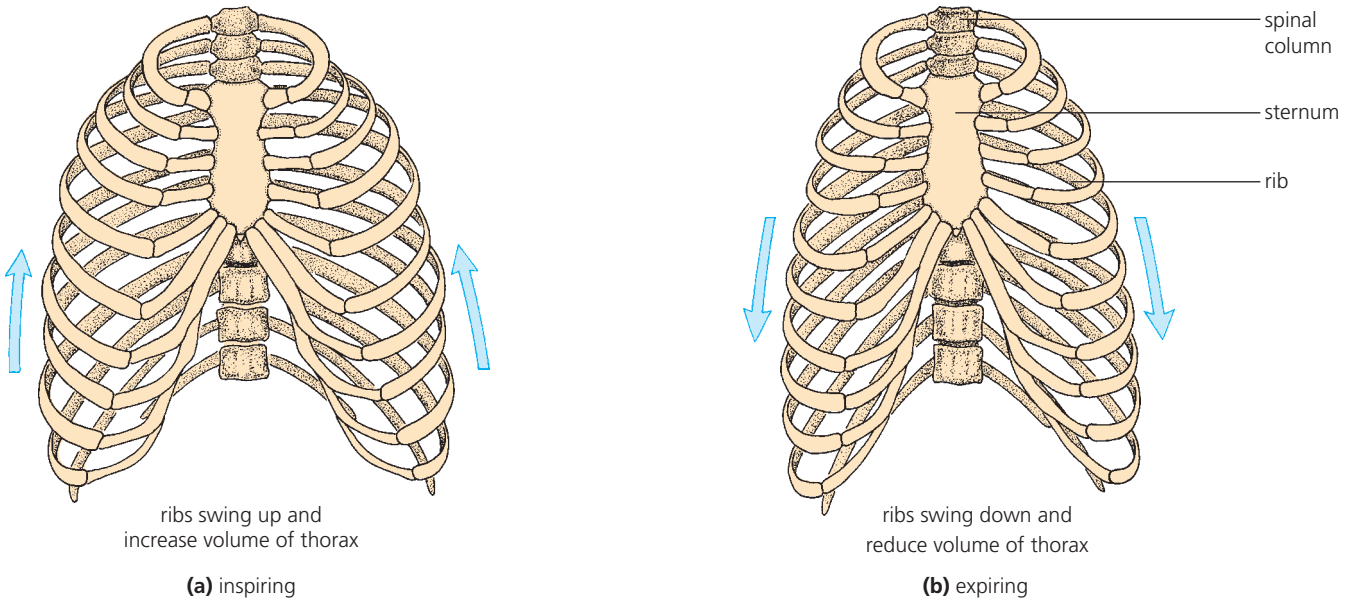
▲ **Figure 9.13** Bell-jar model

When the rubber sheet is pulled down, the volume inside the bell jar increases. This reduces the air pressure inside, making it lower than outside. The air rushes in, through the glass tubing, to equalise the air pressure. This causes the balloons to inflate.

When the rubber sheet is released, the volume inside the bell jar decreases. This increases the air pressure inside, making it higher than outside. The air rushes out, through the glass tubing, to equalise the air pressure. This causes the balloons to deflate.



▲ **Figure 9.14** Diagrams of thorax to show mechanism of breathing



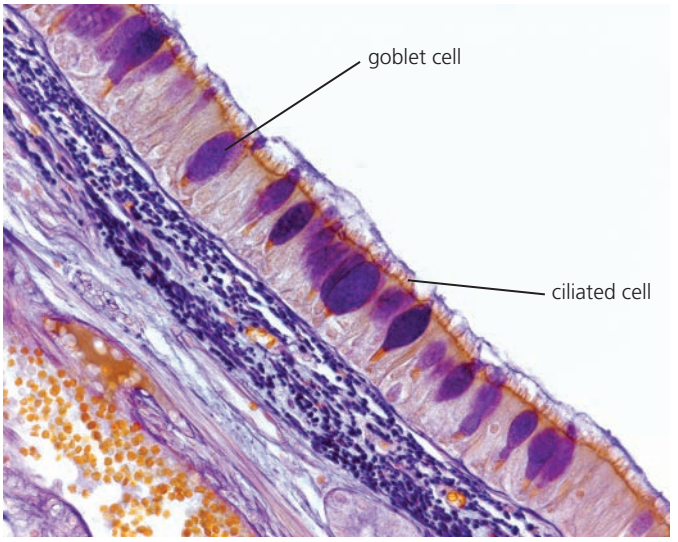
▲ **Figure 9.15** Movement of ribcage during breathing

Protection of the gas exchange system from pathogens and particles

Pathogens are disease-causing organisms (see Chapter 12). Pathogens (e.g. bacteria) and dust particles are present in the air we breathe in and are potentially dangerous if not actively removed. There are two types of cells that are specialised to help do this.

Goblet cells are found in the epithelial lining of the trachea, bronchi and some bronchioles of the respiratory tract (Figure 9.16). Their role is to secrete mucus. The mucus forms a thin film over the internal lining. This sticky liquid traps pathogens and small particles, preventing them from entering the alveoli where they could cause infection or physical damage.

Ciliated cells are also present in the epithelial lining of the respiratory tract (Figure 9.16). They continually move in a flicking motion to move the mucus, secreted by the **goblet cells**, upwards and away from the lungs. When the mucus reaches the top of the trachea it passes down the gullet during normal swallowing.



▲ **Figure 9.16** Goblet cells and ciliated cells in the trachea

Test yourself

8 **a** Compare the bell-jar model in Figure 9.15 with the diagram of the lungs (Figure 9.1). State what the following parts represent on the model.
- **i)** glass tubing
- **ii)** Y-piece
- **iii)** balloons
- **iv)** bell jar
- **v)** rubber sheet

b Explain why this model does not give a complete simulation of the process of breathing.

9 State the two principal muscular contractions that cause air to be inhaled.

10 Place the following in the correct order:
lungs expand, ribs rise, air enters lungs, external intercostal muscles contract, thorax expands.

11 During inhalation, suggest which parts of the lung structure you would expect to expand the most.

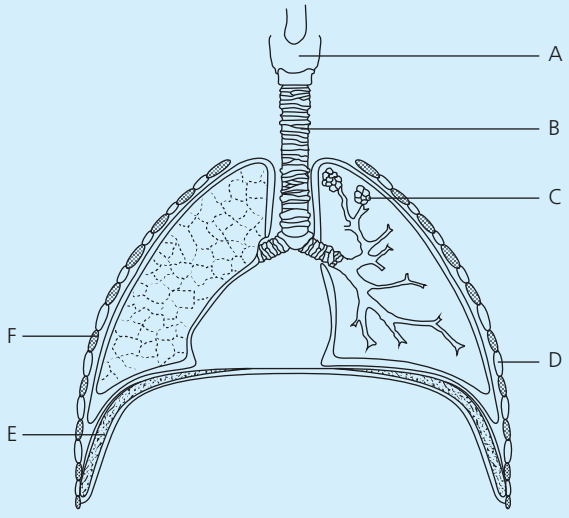
Revision checklist

After studying Chapter 9 you should know and understand the following:

- ✔ Alveoli in the lungs are present in large numbers, provide a large surface area, have a thin surface, have a good blood supply and are well-ventilated with air for efficient gas exchange.
- ✔ The parts of the human breathing system.
- ✔ The position of the intercostal muscles.
- ✔ The functions of cartilage in the trachea and the roles of ribs, intercostal muscles and diaphragm in the ventilation of the lungs.
- ✔ The gases in atmospheric air are 21% oxygen, 78% nitrogen, 0.04% carbon dioxide. The remainder is other gases.
- ✔ Inspired air contains a higher percentage of oxygen and a lower percentage of carbon dioxide and (usually) water vapour than expired air and the reasons why.
- ✔ Limewater is used as a test for the presence of carbon dioxide. It turns milky.
- ✔ During exercise, the rate and depth of breathing increase. This supplies extra oxygen to the muscles and removes their excess carbon dioxide.
- ✔ During physical activity, increases in levels of carbon dioxide in the blood are detected in the brain, causing an increased rate of breathing.
- ✔ Goblet cells make mucus to trap pathogens and particles to protect the gas exchange system.
- ✔ Ciliated cells move mucus away from the alveoli.

Exam-style questions

1 The diagram shows the human breathing system.



a Which labelled part(s)

i) are muscle, to help the process of breathing [2]

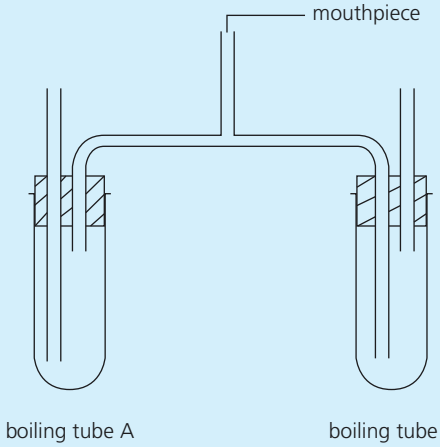
ii) contains rings of cartilage [1]

iii) has a lining covered by mucus to trap bacteria and dust [1]

iv) is closely linked to blood capillaries for gas exchange [1]

v) moves downwards during inspiration. [1]

b The apparatus in the diagram is used to compare the amount of carbon dioxide in the air breathed in with that in the air breathed out.

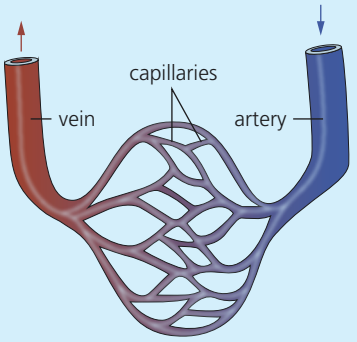


i) Describe how you use the apparatus, including any precautions you would take. [5]

ii) Describe the results you would expect to obtain. [2]

c Outline the effect of exercise on breathing. [2]

2 The diagram shows blood vessels associated with the breathing system of a human.



a i) State the name of the artery. [1]

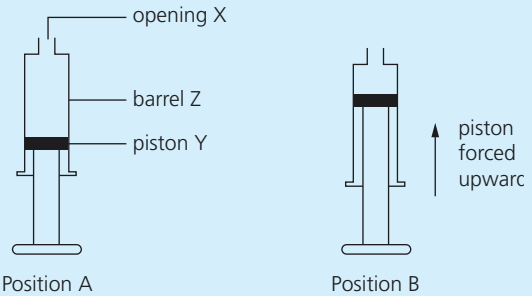
ii) Describe how this artery is different from other arteries. [1]

b i) State what structures in the lungs are embedded in the capillaries. [1]

ii) What process is happening between these structures and the capillaries? [1]

iii) Describe how the structure of capillaries make this process efficient. [3]

3 The diagram shows a model used to demonstrate the action of expiring (breathing out).



a State which part of the breathing system is represented by

i) the opening X [1]

ii) the piston Y [1]

iii) the barrel Z. [1]

b State **three** ways in which the model does not represent the process of expiration in a human. [3]

c With reference to volume and pressure, explain why air is forced out of the syringe when the piston Y is forced upwards. [4]

4 Explain why increased exercise causes an increase in the breathing rate. [4]

5 Construct a table with suitable headings to compare the composition of inspired and expired air, giving reasons for the differences. [8]

10 Respiration

Focus

In the previous chapter we found out about how the breathing system is closely linked to the blood system. You discovered how the lungs are specially adapted to make them efficient in obtaining oxygen and getting rid of carbon dioxide. We are now going to find out more about what cells do with the oxygen the blood brings them. What happens if not enough oxygen is available to meet demand? By the end of the chapter you will have made links between many of the topics we have already studied: nutrition, gas exchange, enzymes and diffusion.

Respiration

FOCUS POINTS

- ★ What do living organisms use energy for?
- ★ What are the effects of temperature on respiration in yeast?

Key definitions

Respiration is described as the chemical reactions in all living cells that release energy from glucose.

Most of the processes taking place in cells need energy to make them happen. Examples of energy-consuming processes in living organisms are

- the contraction of muscle cells – to produce movement of the organism, for peristalsis to move food along the alimentary canal, or contraction of the uterus wall during childbirth
- building up proteins from amino acids
- the process of cell division (Chapter 16) to produce more cells, replace damaged or worn out cells, or to make reproductive cells
- the process of active transport (Chapter 3), involving the movement of molecules across a cell membrane against a concentration gradient
- growth of an organism through the formation of new cells or a permanent increase in cell size
- the conduction of electrical impulses by nerve cells (Chapter 14)
- maintaining a constant body temperature in warm-blooded animals ('Homeostasis' in Chapter 14) to make sure that vital chemical reactions continue at a predictable rate and do not slow down or speed up as the surrounding temperature varies.

This energy comes from the food that cells take in. The food mainly used for energy in cells is glucose. The process by which energy is released from food is called **respiration**.

Respiration is a chemical process that takes place in cells and involves the action of enzymes. It must not be confused with the process of breathing, which is also sometimes called respiration. You should not use the word *respiration* for breathing.

Many enzymes are involved in the chemical reactions of respiration. Low temperatures slow down the rate of respiration in cells because the enzyme and substrate molecules have less kinetic (movement) energy, so there are fewer collisions. As a result, the process of respiration releases less energy for cells. An increase in temperature speeds up respiration because the reacting molecules gain more kinetic energy, resulting in more collisions. Consequently, more energy is released through the process of respiration. However, above the optimum temperature for the enzymes, the rate of respiration starts to reduce because the enzyme molecules begin to be denatured. The enzyme molecules are not all denatured at the same temperature, so the reduction in rate of respiration is gradual as the temperature increases. Once all the enzymes involved in respiration have become denatured, respiration will stop. It is important that yeast is not mixed in boiling water when used for processes such as bread-making, because the respiratory enzymes in the cells would be denatured and the cells would be killed.

Practical work

Safety

- Eye protection must be worn.

Experiments on the effect of temperature on respiration in yeast

1 The effect of temperature on yeast respiration

- Make some bread dough using flour, water and activated yeast (yeast in a warm sugar solution).
- Rub the inside of a boiling tube or measuring cylinder with oil (this makes it easier to remove the dough after the experiment).
- Use a glass rod or the end of an old pencil to push a piece of dough into the bottom of the boiling tube, so that the tube is about a quarter full of dough.
- Mark the height of the top of the dough on the boiling tube or measuring cylinder using a chinagraph pencil or permanent marker pen.
- Place the boiling tube into a beaker of water set to a preselected temperature (e.g. 20 °C).
- Leave the dough for 20 minutes, checking to make sure the temperature of the water-bath remains constant (add warm or cold water to maintain this).
- Record the new height of the dough.
- Repeat the method at different temperatures and compare the rate at which the bread dough rises.

Results

The dough rises faster as the temperature is increased to 35 or 40 °C. Higher temperatures slow down the rate. Low temperatures may result in no change in the height of the dough.

Interpretation

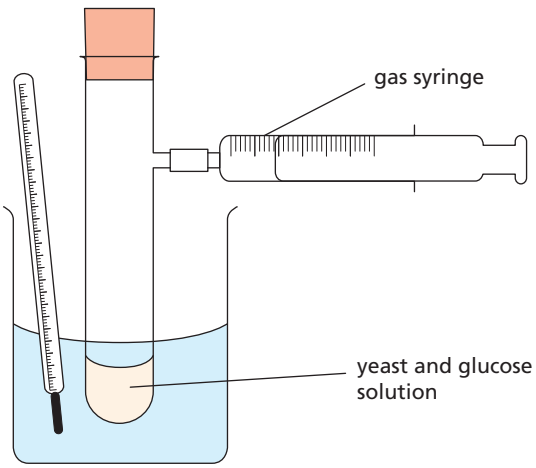
Yeast respires anaerobically, producing carbon dioxide. This causes the dough to rise. The process is controlled by enzymes, which work faster as the temperature is increased to the optimum (around 35–40 °C). Higher temperatures cause the enzymes to denature (Chapter 5).

2 The effect of temperature on yeast respiration (alternative method)

- Make up a 5% solution of glucose and a 10% suspension of dried yeast.
- Place 5 cm^3 of the glucose solution and 1 cm^3 of the yeast suspension in a side-arm boiling tube or conical flask. (If a conical flask is used, add larger volumes of the glucose solution and yeast suspension, keeping the proportions the same).
- Place the container with the yeast and glucose in a beaker of water at 20 °C.
- Leave the apparatus for a few minutes to allow the yeast to adjust to the temperature of the water in the beaker.
- Attach the side arm to a gas syringe, with the plunger pushed fully in.
- Start a stopwatch and allow the gas produced by yeast to collect in the gas syringe for a fixed time.
- Record the time and the volume of gas produced.
- Repeat for a range of different temperatures.

Calculate the gas production per minute for each temperature.

Note: If a gas syringe is not available, the side arm could be attached to a delivery tube inserted into a boiling tube containing water. Count the bubbles produced for a fixed time.



▲ **Figure 10.1** Experiment to investigate the effect of temperature on respiration in yeast

Results

The volume of gas produced increases as the temperature is increased to 35 or 40 °C. Higher temperatures slow down the rate of gas production. Low temperatures may result in less gas being produced.

Interpretation

Yeast respires, producing carbon dioxide. This causes the formation of gas, which collects in the gas syringe. The process is controlled by enzymes, which work faster as the temperature is increased to the optimum (around 35–40 °C). Higher temperatures cause the enzymes to denature (Chapter 5), so the rate of carbon dioxide production slows down.

Practical work questions

1 A student carried out experiment 1 with five boiling tubes set up at different temperatures. What would she need to keep the same to make sure the results were comparable?

2 **a** For experiment 2, describe the test you would carry out on the gas being produced to show that it was carbon dioxide.

b What result would you expect to get?

Test yourself

1 **a** Choose one word from the list that describes what respiration is about: breathing, energy, oxygen, cells, food.

b State in which parts of a living organism respiration takes place.

2 Which of the following statements are true? If an organism is respiring, you would expect it to be

a giving out carbon dioxide
b losing heat
c breaking down food
d using up oxygen
e gaining weight
f moving about.

3 Victims of drowning who have stopped breathing are sometimes revived by a process called artificial respiration. Suggest why a biologist would object to the use of this expression. (Resuscitation is a better word to use.)

4 The table below shows the energy used up each day as kilojoules per kilogram of body mass and as kilojoules per square metre of body surface.

animal	mass/kg	kJ per day	
		per kg body mass	per m² body surface
man	64.3	134	4360
mouse	0.018	2736	4971

a Using figures from the table, calculate the total amount of energy used each day by
i) a man
ii) a mouse.

b State which of these two mammals shows a greater rate of respiration in its body cells.

c Suggest why the mouse has a much greater energy use per kg of body mass than the man.

Aerobic respiration

FOCUS POINTS

- ★ What is aerobic respiration?
- ★ What is the word equation for aerobic respiration?
- ★ What is the balanced chemical equation for aerobic respiration?

Key definitions

Aerobic respiration is the release of a relatively large amount of energy by the breakdown of glucose in the presence of oxygen.

The word **aerobic** means that oxygen is needed for this chemical reaction. The food molecules are combined with oxygen. All food molecules contain carbon, hydrogen and oxygen atoms. The process of **oxidation** converts the carbon to carbon dioxide (CO_2) and the hydrogen to water (H_2O) and, at the same time, releases energy, which the cell can use to drive other reactions.

Aerobic respiration can be summed up by the equation

$$\text{glucose} + \text{oxygen} \xrightarrow{\text{enzymes}} \text{carbon dioxide} + \text{water} + \textbf{ENERGY released}$$

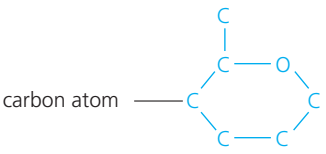
The balanced chemical equation for aerobic respiration is:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \rightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{energy released}}{2\,830\ \text{kJ}}$$

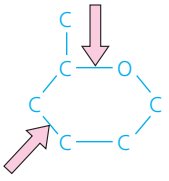
Going further

The amount of energy you would get by completely oxidising 180 grams (1 mol) of glucose to carbon dioxide and water is 2830 kilojoules (kJ). In the cells, the energy is not released all at once. The oxidation takes place in a series of small steps and not in one jump as the equation suggests. Each small step needs its own enzyme and at each stage a little energy is released (Figure 10.2). Although the energy is used for the processes mentioned above, some of it always appears as heat.

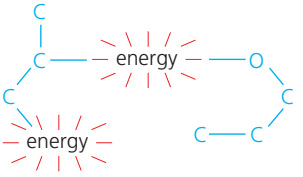
In warm-blooded animals (e.g. birds and mammals) some of this heat is needed to maintain their body temperature.
In cold-blooded animals (e.g. amphibians, reptiles and fish) the heat may build up for a time in the body and allow the animal to move about more quickly.
In plants the heat is lost to the surroundings (by conduction, convection and evaporation) as fast as it is produced.



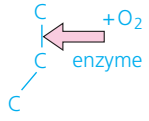
(a) molecule of glucose (H and O atoms not all shown)



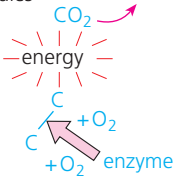
(b) the enzyme attacks and breaks the glucose molecule into two 3-carbon molecules



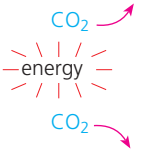
(c) this breakdown sets free energy



(d) each 3-carbon molecule is broken down to carbon dioxide



(e) more energy is released and CO_2 is produced



(f) the glucose has been completely oxidised to carbon dioxide (and water) and all the energy released

▲ **Figure 10.2** Aerobic respiration

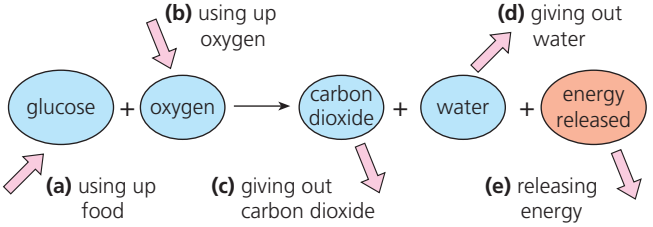
Practical work

Safety

- Eye protection must be worn.

Experiments on respiration and energy

If you look below at the chemical equation that represents aerobic respiration you will see that a tissue or an organism that is respiring should be (a) using up food, (b) using up oxygen, (c) giving off carbon dioxide, (d) giving out water and (e) releasing energy, which can be used for other processes.



If we wish to test whether aerobic respiration is taking place:

- '(d) giving out water' is not a good test because non-living material will give off water vapour if it is wet to start with.
- '(a) using up food' can be tested by seeing if an organism loses weight. This is not as easy as it seems because most organisms lose weight as a result of evaporation of water and this may have nothing to do with respiration. It is the decrease in 'dry weight' that must be measured.

We will focus on the uptake of oxygen and the production of carbon dioxide as indications that respiration is taking place.

Seeds are often used as the living organisms in such experiments because when they start

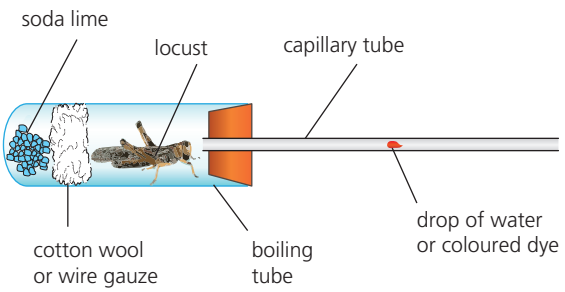
to grow (germinate) there is a high level of chemical activity in the cells. Seeds are easy to obtain and to handle and they fit into small-scale apparatus. In some cases blowfly maggots or woodlice can be used as animal material. Yeast is useful when studying **anaerobic respiration**.

3 Using up oxygen during respiration

The apparatus in Figure 10.3 is a simple **respirometer** (a 'respire meter'), which can measure the rate of respiration by seeing how quickly oxygen is taken up. Germinating seeds, blowfly larvae or a locust are placed in the boiling tube and, as they use up the oxygen for respiration, the liquid in the capillary tube will move towards the organism.

There is a drawback to this. The organisms usually give out as much carbon dioxide as they take in oxygen. So, there may be no change in the total amount of air in the boiling tube and the liquid drop will not move. This drawback is overcome by placing soda lime in the boiling tube. Soda lime will absorb carbon dioxide as fast as the organisms give it out, so only the uptake of oxygen will affect the amount of air in the tube.

- A larger invertebrate such as a locust, a group of blowfly maggots or germinating seeds are placed in the boiling tube (an alternative is a large plastic syringe linked to the capillary tube with a short section of rubber or silicone tubing). The organisms are protected from the soda lime by cotton wool or a wire gauze (soda lime is corrosive).



▲ **Figure 10.3** A simple respirometer

- A drop of water or coloured dye is introduced to the capillary tube by touching it against the liquid.
- The capillary tube is rested against a ruler and the position of the water drop is noted.
- After 1 minute (or longer if the drop moves very slowly) the new position of the water drop is recorded.

Note: Care must be taken when handling living organisms. Wash your hands thoroughly with water if they come into contact with soda lime.

Control

To show that it is a living process that uses up oxygen, a second simple respirometer is set up using the same apparatus, but with glass beads instead of the organism(s). (This is not a very good control but is more acceptable than killing animals.) The bubble may still move because the soda lime will absorb any carbon dioxide in the air in the boiling tube, but the movement should be less than the movement for living organisms.

Results

The water drop moves towards the organism. If the diameter of the bore of the capillary tube is measured, the volume of air taken in by the organism can be calculated:

$$\text{volume} = \pi r^2 l$$

where r = radius of the capillary tube bore

l = distance travelled by the water drop.

This value can be converted into a rate if the volume is divided by the time taken.

Interpretation

The movement of the water drop towards the organism shows that it is taking in air. By using a range of organisms (locust, woodlice, blowfly larvae, germinating seeds) the rates of uptake can be compared to see which is respiring most actively.

Worked example

The capillary tube had a bore with a diameter of 0.5 mm.

The water drop moved 4.2 cm in 5 minutes.

Calculate

a the volume of air taken up by the organism

b the rate of uptake of air.

First, make sure all the units are suitable. We have a diameter in millimetres and a distance in centimetres. So, change the distance to millimetres.

$4.2 \times 10 = 42$ mm

For the calculation we need to know the radius of the capillary tube bore. Its diameter is 0.5 mm.

The radius = $0.5 \div 2 = 0.25$ mm

Volume = $\pi r^2 l$, where $r = 0.25$ mm and $l = 42$ mm

So, volume = $3.142 \times (0.25)^2 \times 42$

$= 0.66$ mm^3 in 5 minutes.

To calculate the rate of uptake of the air, this volume needs to be divided by the time, which was 5 minutes.

$8.25 \div 5 = 1.65$ mm^3 min^{-1}

Tasks

1 In an experiment using 20 germinating seeds in a simple respirometer, the capillary tube had a bore with a diameter of 1.0 mm.
The drop of coloured dye moved 2.55 cm in 10 minutes.
Calculate
a the volume of air taken up by the seeds
b the volume of air taken up by one seed
c the rate of uptake of air by one seed. Give your answer in standard form.

Practical work

Safety

- Eye protection must be worn.
- Take care when using and handling hot and boiling water.

4 Investigating the effect of temperature on the rate of respiration of germinating seeds

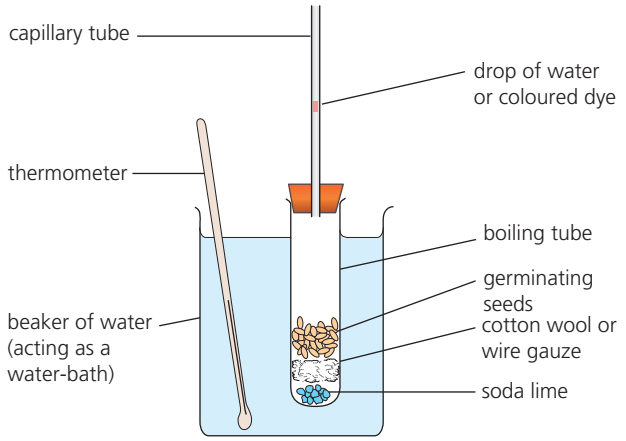
- Use the same apparatus as shown in experiment 3 but set up the boiling tube so it is vertical and supported in a water-bath, for example, a beaker (Figure 10.4).
- Use wheat grains or pea seeds that have been soaked for 24 hours and rinsed in domestic bleach diluted 1:4 for 5 minutes. This solution will kill any bacteria or fungi on the surface of the seeds.
- Kill an equal quantity of soaked seeds by boiling them for 5 minutes.
- Cool the boiled seeds in cold tap water then rinse them in bleach for 5 minutes as before. These can be used as the control (or, alternatively, use the same volume of glass beads).
- Start with a water-bath at about 20 °C and allow the seeds to adjust to that temperature for a few minutes before taking any readings.
- The initial and final positions of the water drop could be recorded on the capillary tube. You can do this with a permanent marker or chinagraph pencil, or by sticking a small label onto the glass. You can then measure the distance travelled with a ruler.
- Repeat the method (introducing a new bubble each time) at a range of different temperatures, remembering to allow time for the seeds to adjust to the new conditions before taking more readings.

Results

As the temperature is increased the rate of movement of the water bubble towards the seeds increases. The movement may stop at higher temperatures.

Interpretation

As the temperature increases, the rate of respiration in the germinating seeds increases. This is because the enzymes controlling respiration are more active at higher temperatures. However, respiration may stop above around 40 °C because the enzymes become denatured if they get too hot.



▲ **Figure 10.4** Simple respirometer for investigating the effect of temperature on germinating seeds

Practical work questions

3 In experiment 3, the drop of coloured dye moved 2.5 cm in 5 minutes. The diameter of the capillary tubing was 1 mm.
Calculate the rate of uptake of oxygen by the locust.

4 For experiment 4:
- **a** Explain why the killed seeds were rinsed in bleach.
- **b** Suggest what the result might be if the bleach had not been used on these seeds.

Test yourself

5 **a** State what chemical substances must be provided for aerobic respiration to take place
- **i)** from outside the cell
- **ii)** from inside the cell.

b What are the products of aerobic respiration?

6 **a** Explain why soda lime was used in the respirometer in Figure 10.3.

b Describe what test you would carry out to show that an organism produces carbon dioxide when it respires.

7 In an experiment like the one shown in Figure 10.3, growing seeds took in 5 cm^3 oxygen and gave out 7 cm^3 carbon dioxide. How does the volume change
- **a** if no soda lime is present
- **b** if soda lime is present?

Anaerobic respiration

FOCUS POINTS

- ★ What is anaerobic respiration?
- ★ How much energy does anaerobic respiration release compared to aerobic respiration per glucose molecule?
- ★ What is the word equation for anaerobic respiration in yeast?
- ★ What is the word equation for anaerobic respiration in humans?
- ★ What causes an oxygen debt during vigorous exercise?
- ★ How is the oxygen debt removed after exercise?

Key definitions

Anaerobic respiration is the release of a relatively small amount of energy by the breakdown of glucose without using oxygen.

The word anaerobic means *in the absence of oxygen*. In this process, energy is still released from food by breaking it down chemically. The reactions do not use oxygen but they do often produce carbon dioxide. A common example is the action of yeast on sugar solution to produce alcohol. The sugar is not completely oxidised to carbon dioxide and water. Instead, it is converted to carbon dioxide and alcohol. This process is called fermentation and is shown by the following equation:

$$\text{glucose} \xrightarrow{\text{enzymes}} \text{alcohol} + \text{carbon dioxide} + \textbf{ENERGY released}$$

The processes of making ethanol and bread-making (see Chapter 18) rely on anaerobic respiration by yeast. Like aerobic respiration, the reaction takes place in small steps and needs several different enzymes. The yeast uses the energy for its growth and living processes, but much less energy is released by anaerobic respiration than in aerobic respiration. This is because the alcohol still contains a lot of energy that the yeast is unable to use.

Anaerobic respiration also happens in muscles during vigorous exercise, because oxygen cannot be delivered fast enough for the muscle cells to respire aerobically. The products are different to those produced by anaerobic respiration in yeast. The process is shown by the following equation:

glucose → lactic acid

Anaerobic respiration is much less efficient than aerobic respiration because it releases much less energy (118 kJ) per 180 grams of glucose (1 mol) broken down.

During vigorous exercise, **lactic acid** may build up in a muscle. In this case it is removed in the bloodstream. The blood needs to move more quickly during and after exercise to maintain this lactic acid removal process, so the heart rate is rapid. On reaching the liver, some of the lactic acid is respired aerobically. This produces carbon dioxide and water and uses oxygen in the process. After exercise has stopped, a high level of oxygen consumption may continue until the excess of lactic acid has been broken down. As a result, the person who is exercising breathes faster and more deeply (an athlete pants for breath rapidly). The build-up of lactic acid that is oxidised later is called an **oxygen debt**. An alternative term for this is Excess Post-exercise Oxygen Consumption (or EPOC). EPOC is the amount of oxygen needed to return the body to its normal, resting level of metabolic function (an example of **homeostasis**, see Chapter 14). It is important because build-up of lactic acid in the muscles results in muscular fatigue, leading to cramp.

Going further

Athletes and climbers who are used to working at low altitude (normal air pressure) have problems if they then perform at high altitude (low air pressure). High-altitude air has a lower percentage of oxygen, so an oxygen debt can be experienced much more easily than at low altitude. The problem can be overcome if the person spends time at high altitude before performing to allow the body to adjust (making more red blood cells and increasing blood volume).

Practical work

Safety

- Eye protection must be worn.
- Take care when using and handling hot and boiling water.

More experiments on respiration and energy

5 Releasing energy in respiration

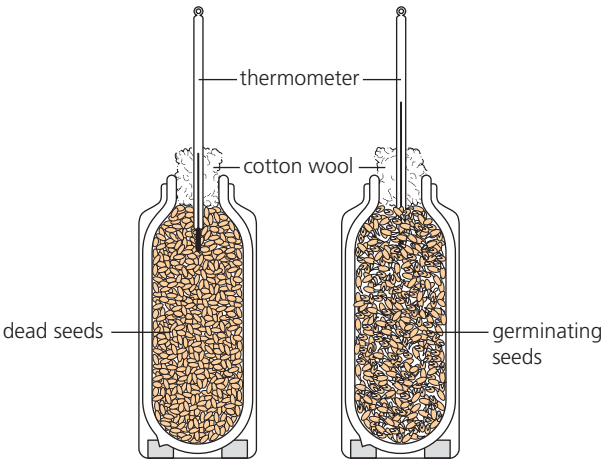
- Fill a small vacuum flask with wheat grains or pea seeds that have been soaked for 24 hours and rinsed in domestic bleach diluted 1:4 for 5 minutes. This solution will kill any bacteria or fungi on the surface of the seeds.
- Kill an equal quantity of soaked seeds by boiling them for 5 minutes.
- Cool the boiled seeds in cold tap water, rinse them in bleach for 5 minutes as before and then put them in a vacuum flask that is the same size as the first one. This flask is the control.
- Place a thermometer in each flask so that its bulb is in the middle of the seeds (Figure 10.5).
- Block the mouth of each flask with cotton wool and leave both flasks for 2 days, noting the thermometer readings whenever possible.

Results

The temperature in the flask with the living seeds will be 5–10 °C higher than the temperature of the flask containing the dead seeds.

Interpretation

If there are no signs of the living seeds going mouldy, the heat released must have come from living processes in the seeds. This is because the dead seeds in the control did not give out any heat. There is no evidence that this process is respiration rather than any other chemical change, but the result is what you would expect if respiration does release energy.



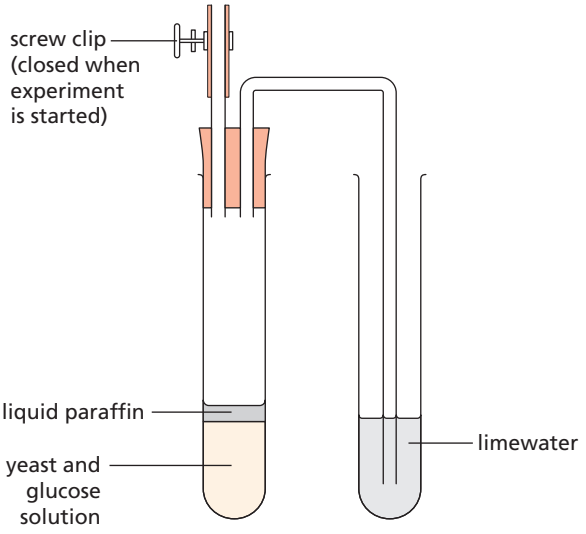
▲ **Figure 10.5** Experiment to show energy release in germinating seeds

6 Anaerobic respiration in yeast

- Boil some water to remove all the dissolved oxygen.
- When cool, use the boiled water to make up a 5% solution of glucose and a 10% suspension of dried yeast.
- Place 5 cm^3 of the glucose solution and 1 cm^3 of the yeast suspension in a test tube and cover the mixture with a thin layer of liquid paraffin to exclude atmospheric oxygen.
- Fit a delivery tube as shown in Figure 10.6 and allow it to dip into clear limewater.

Results

After 10–15 minutes, with gentle warming if necessary, there should be signs of fermentation in the yeast–glucose mixture and the bubbles of gas escaping through the limewater should turn it milky.



▲ **Figure 10.6** Experiment to show anaerobic respiration in yeast

Interpretation

The fact that the limewater goes milky shows that the yeast–glucose mixture is producing carbon dioxide. If we assume that the production of carbon dioxide is evidence of respiration then it suggests that the yeast is respiring. In setting up the experiment, you took care to make sure that oxygen was removed from the glucose solution and the yeast suspension, and the liquid paraffin excluded air (including oxygen) from the mixture. So, any respiration taking place must be anaerobic (i.e. without oxygen).

Control

One possibility is that the carbon dioxide came from a chemical reaction between yeast and glucose (like the reaction between chalk and acid), which had nothing to do with respiration or any other living process. So, a control should be set up using the same method as before, but with yeast that has been killed by boiling. If no carbon dioxide is produced, this supports the claim that it was a living process in the yeast in the first experiment that produced the carbon dioxide.

Practical work questions

5 In experiment 5, why are vacuum flasks used in this investigation?

6 In experiment 6, state the functions of
- **a** the liquid paraffin
- **b** the limewater
- **c** the glucose.

Test yourself

8 State the main differences between aerobic and anaerobic respiration.

9 Explain why your breathing rate and heart rate stay high for some time after completing vigorous exercise.

10 Explain why lactic acid builds up in the muscles during vigorous exercise.

Going further

Hypothesis testing

You will have noticed that none of the experiments described above claim to have *proved* that respiration is taking place. The most we can claim is that they have not disproved the proposal that energy is released from respiration. There are many reactions taking place in living organisms and, for all we know at this stage, some of them may be using oxygen or giving out carbon dioxide without releasing energy, i.e. they would not fit our definition of respiration.

This inability to 'prove' that a particular proposal is true is not limited to experiments on respiration. It is a feature of many scientific experiments. One way in which science makes progress is by writing a hypothesis, making predictions from the hypothesis, and then testing these predictions by experiments.

A hypothesis is an attempt to explain an event or observation using the information currently available. If an experiment's results do not confirm the predictions, the hypothesis must be abandoned or changed.

For example, biologists observing that living organisms take up oxygen might put forward the hypothesis that 'oxygen is used to convert food to carbon dioxide, so producing energy for movement, growth, reproduction, etc.'. This hypothesis can be tested by predicting that, '*if* the oxygen is used to oxidise food *then* an organism that takes up oxygen will also produce carbon dioxide'. Experiment 3 on page 156 tests this and achieves this prediction, and so it supports the hypothesis. Looking at the equation for respiration, we might also predict that an organism that is respiring will produce carbon dioxide and take up oxygen. Experiment 6 with yeast, however, does not achieve this prediction and so does not support the hypothesis, because here is an organism producing carbon dioxide without taking up oxygen. The hypothesis will have to be changed, for example, 'energy is released from food by breaking it down to carbon dioxide; some organisms use oxygen for this process, others do not'.

There are still plenty of tests that we have not done. For example, we have not tried to see whether food is the source of energy and carbon dioxide. One way of doing this is to provide the organism with food (e.g. glucose) in which the carbon atoms are radioactive. Carbon-14 (^{14}C) is a radioactive form of carbon and can be detected by using a Geiger counter. If the organism produces radioactive carbon dioxide, it is reasonable to accept that the carbon dioxide comes from the glucose.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy released}$$

This is direct evidence in support of the hypothesis. All the previous experiments have only provided indirect evidence.

Criteria for a good hypothesis

A good hypothesis must

- explain *all* aspects of the observation
- be the simplest possible explanation
- be stated in such a way that predictions can be made from it
- be testable by experiment.

Revision checklist

After studying Chapter 10 you should know and understand the following:

- ✔ Respiration is the chemical reactions in living cells that release energy from glucose.
- ✔ Living organisms use the energy released in respiration for processes such as muscle contraction, protein synthesis, cell division, active transport, growth, the passage of nerve impulses and the maintenance of a constant body temperature.
- ✔ An increase in temperature to 35–40 °C increases the rate of respiration of yeast.
- ✔ Aerobic respiration is the release of a relatively large amount of energy by breaking down glucose in the presence of oxygen.
- ✔ The word equation for aerobic respiration is

glucose + oxygen → carbon dioxide + water

- ✔ The balanced chemical equation for aerobic respiration is

  $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
- ✔ Anaerobic respiration is the release of a relatively small amount of energy by the break-down of glucose without using oxygen.
- ✔ The word equation for anaerobic respiration in yeast is

  glucose → ethanol + carbon dioxide
- ✔ The word equation for anaerobic respiration in humans is

  glucose → lactic acid
- ✔ Aerobic respiration releases much more energy per glucose molecule than anaerobic respiration.
- ✔ Lactic acid builds up in muscles due to anaerobic respiration, causing Excess Post-exercise Oxygen Consumption (EPOC), or an oxygen debt.
- ✔ A fast heart rate and deeper breathing helps remove lactic acid by aerobic respiration in the liver during recovery.

Exam-style questions

1 Match the processes to their products. Products may be linked once or more than once. [5]

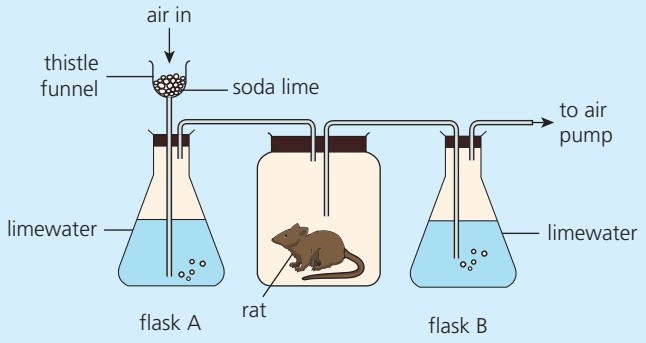
process	product
aerobic respiration	alcohol
anaerobic respiration in yeast	carbon dioxide
anaerobic respiration in muscles	lactic acid
	water

2 **a** Define the term *respiration*. [3]

b Distinguish between aerobic respiration and anaerobic respiration in muscles. [4]

c Energy is used for the contraction of muscles. State **four** other uses of energy in living organisms. [4]

3 The diagram shows an investigation into respiration in a mammal.



a The soda lime was weighed then placed in the thistle funnel. At the end of the investigation it was weighed again.

i) State the function of the soda lime. [1]

ii) Suggest how the mass of the soda lime at the end of the investigation was different to its mass at the start. Explain your answer. [2]

b Describe and explain what happened to the limewater at the end of the investigation

i) in flask A [2]

ii) in flask B. [2]

c Suggest why flask A was included in the investigation. [2]

4 What is/are the product(s) of anaerobic respiration in yeast?

A lactic acid only
B carbon dioxide and water
C carbon dioxide and ethanol
D ethanol only [1]

5 Where is the site of respiration in a cell?

A nucleus
B mitochondrion
C chloroplast
D cell membrane [1]

6 An athlete who completes a sprint relies on anaerobic respiration for his muscles to continue working. Describe what happens in his muscles and bloodstream during and after the sprint. [8]

11 Transport in humans

Focus

In Chapter 2 you were introduced to some single-celled organisms that can obtain what they need by diffusion. In Chapter 7 you found out how plants can obtain and move materials around the organism without the need for a pump. Now we can start to look at other multicellular organisms and how their bodies have developed to move materials efficiently to where they need to be. Are there any similarities between transport in plants and animals? You will soon find the answers.

Circulatory systems

FOCUS POINTS

- ★ What is the circulatory system?
- ★ What is the double circulation of a mammal?
- ★ What are the advantages of a double circulation?

Key definitions

The **circulatory system** is a system of blood vessels with a pump and valves to ensure a one-way flow of blood.

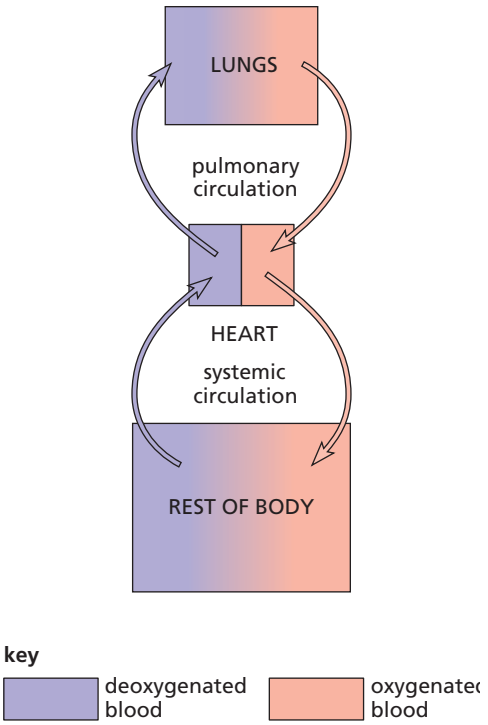
Double circulation is a system in which blood passes through the heart twice for each complete circuit.

The blood, pumped by the heart, travels all around the body in blood vessels. It leaves the heart in **arteries** and returns in veins. Valves, present in the heart and veins, ensure a one-way flow of the blood. As blood enters an organ, the arteries divide into smaller vessels, which supply capillaries. In these vessels the blood moves much more slowly, allowing the exchange of materials like oxygen and glucose, carbon dioxide and other wastes. Blood leaving an organ is collected in veins.

Double circulation of mammals

Double circulation is a system in which blood passes through the heart twice for each complete circuit. The route of the circulation of blood in a mammal is shown in Figure 11.1.

The blood passes twice through the heart during one complete circuit: once on its way to the body and again on its way to the lungs. On average, a red blood cell would go around the whole circulation in 45 seconds. A more detailed diagram of the circulation is shown in Figure 11.17.



▲ **Figure 11.1** Double circulation of a mammal

A double circulation has the advantage of maintaining a high blood pressure to all the major organs of the body. The right side of the heart collects blood from the body and builds up the blood pressure enough to send it to the lungs to be oxygenated. The pressure drops during this process. The left side of the heart receives oxygenated blood from the lungs, builds up the blood pressure again, but higher, and pumps the oxygenated blood to the body.

Test yourself

1 State why there are valves present in a circulatory system.

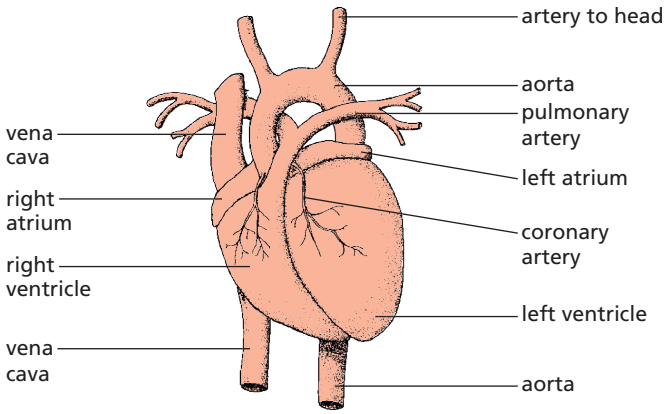
2 Suggest why some small organisms do not need a circulatory system.

Heart

FOCUS POINTS

- ★ What is the structure of the mammalian heart?
- ★ Where is blood pumped?
- ★ Why is the muscle wall of the left ventricle thicker than that of the right ventricle?
- ★ Why are the muscle walls of the ventricles thicker than those of the atria?
- ★ How does the heart function in terms of the contraction of muscles of the atria and ventricles and the action of the valves in a heartbeat?
- ★ Why does physical activity affect heart rate?
- ★ How can the heart be monitored?
- ★ What is the effect of physical activity on the heart rate?
- ★ What is coronary heart disease and what are the risk factors?
- ★ What are the roles of diet and exercise in reducing the risk of coronary heart disease?

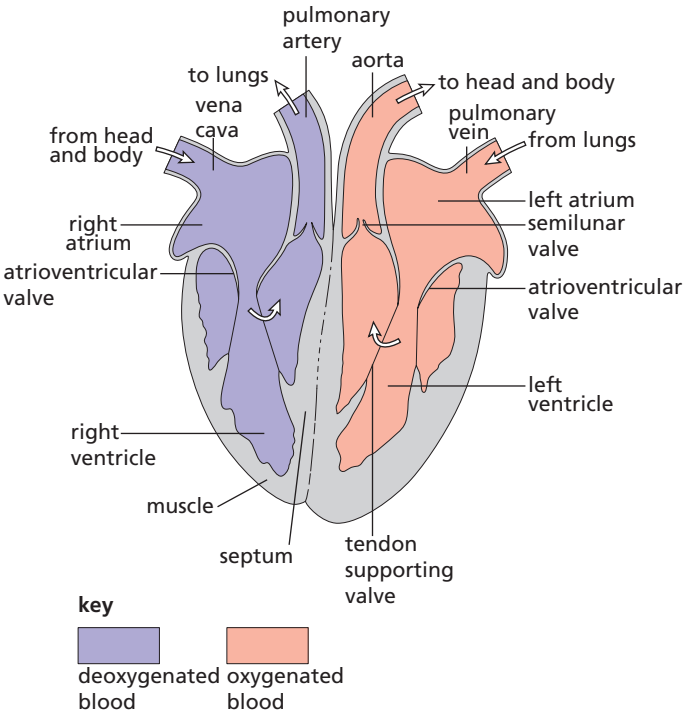
The heart pumps blood through the circulatory system to all the main organs of the body. The appearance of the heart from the outside is shown in Figure 11.2. Figure 11.3 is a diagram of a vertical section to show its internal structure. As the heart is seen like it would be in a dissection of a person facing you, the left side is drawn on the right. Make sure you remember this whenever you are labelling parts of the heart on a diagram.



▲ **Figure 11.2** External view of the heart

If you look at Figure 11.3 you will see that there are four chambers. The upper, thin-walled chambers are the atria (singular = atrium) and each of these opens into a thick-walled chamber, the ventricle, below.

Blood is pumped away from the heart in arteries and returns to the heart in veins. The blood enters the atria from large veins. The pulmonary vein brings oxygenated blood from the lungs into the left atrium. The **vena cava** brings deoxygenated blood from the body tissues into the right atrium. The blood passes from each atrium to the ventricle below it, and the ventricle pumps it out into the arteries. The left chambers are separated from the right chambers by a wall of muscle called a **septum**.



▲ **Figure 11.3** Diagram of the heart, vertical section

The artery carrying oxygenated blood to the body from the left ventricle is the **aorta**. The pulmonary artery carries deoxygenated blood from the right ventricle to the lungs.

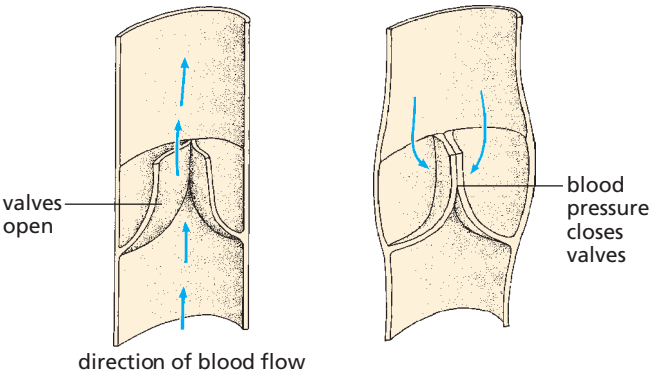
In pumping the blood, the muscle in the walls of the atria and ventricles contracts and relaxes (Figure 11.3). The walls of the atria contract first and force blood into the two ventricles. Then the ventricles contract and send blood into the arteries. Valves prevent blood flowing backwards during or after heart contractions.

The heart muscle is supplied with food and oxygen by the **coronary arteries** (Figure 11.2).

Control of blood flow through the heart

Four sets of valves stop the blood from flowing backwards. Valves that separate each atrium from the ventricle below it are called **atrioventricular valves**. The flaps of these valves are shaped like parachutes, with strings called tendons or cords to stop them being turned inside-out.

In the pulmonary artery and aorta are the **semilunar** (= half-moon) **valves**. These are made of three 'pockets', which are pushed flat against the artery walls when blood flows one way. If blood tries to flow the other way, the pockets fill up and meet in the middle to stop the flow of blood (Figure 11.4).



▲ **Figure 11.4** Action of the semilunar valves

The heartbeat is started by the 'pacemaker', a small group of specialised muscle cells at the top of the right atrium. These fire an impulse. The impulse spreads through the walls of the right and left atria, causing them to contract. This forces blood into the ventricles. The impulse carries on to the ventricles (Figure 11.6). When the ventricles contract, the atrioventricular valves close because of the blood pressure. These valves stop blood returning to the atria. When the ventricles relax, the semilunar valves close because of the blood pressure in the arteries, so they stop blood going back into the ventricles.

The atria have much thinner muscle walls than the ventricles. When the ventricles relax, their internal volume increases and they fill with blood from the pulmonary vein or vena cava through the relaxed atria. The atria then contract and force the final amount of blood into the ventricles just before ventricular contraction.

The wall of the left ventricle (sometimes called the 'large left ventricle') is made of cardiac muscle. This is about three times thicker than the wall of the right ventricle. The reason for the difference is because the right ventricle only needs to produce enough pressure to pump blood to one organ, the lungs, which are next to the heart. However, the left ventricle needs to pump blood to all the main organs of the body, as shown in Figure 11.17. *It is important to understand that the left and right ventricles pump the same volume of blood:* the left ventricle does *not* have a thicker wall to pump *more* blood!

The right side of the heart is separated from the left side by the septum. This prevents deoxygenated blood from mixing with oxygenated blood.

Practical work

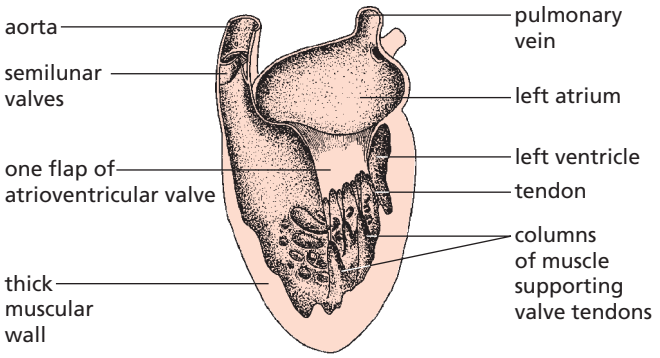
(This activity is optional. If you are asked to undertake this activity and you are uncomfortable about doing it, you should raise your concerns with your teacher.)

Safety

- Eye protection must be worn.
- Take care when using a scalpel, follow your teacher's guidance.

1 Heart dissection

- Obtain an intact heart (sheep or goat, for example) from a butcher's shop or abattoir.
- Rinse it under a tap to remove excess blood.
- Observe the surface of the heart, identifying the main features you can see (shown in Figure 11.2). The blood vessels may have been cut off, but it is possible to identify where these would have been attached later in the dissection.
- Gently squeeze the ventricles. They can be recognised because the wall of the right ventricle is much thinner than the wall of the left ventricle.
- Using a pair of sharp scissors or a scalpel, make a cut from the base of the left ventricle, up through the left atrium.
- Using a pair of forceps, remove any blood clots lying in the chambers you have cut open.
- Identify the main features as shown in Figure 11.5.



▲ **Figure 11.5** Diagram of the heart cut open (left side)

- If you have not cut open the aorta, gently push the handle of a blunt seeker or an old pencil behind the bicuspid valve. It should find its way into the aorta. Note how thick the wall of this blood vessel is.
- Compare the semilunar valves in the base of the aorta with the atrioventricular valve between the atrium and ventricle. Note that the atrioventricular valve has tendons to stop it turning inside-out.
- Now repeat the method on the right side of the heart to open the right atrium and ventricle.
- Pushing the handle of the seeker behind the atrioventricular valve should allow it to enter the pulmonary artery. Cut open the artery to find semilunar valves. Note the relative thinness of the wall, compared to the wall of the aorta.
- Also compare the thickness of the left ventricle wall to the wall of the right ventricle.

Practical work question

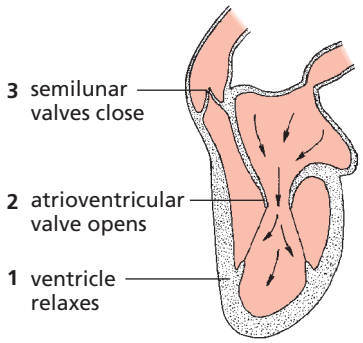
1 Describe the difference(s) between
   - **a** the atrioventricular valves (those between each atrium and ventricle) and the semilunar valves
   - **b** the atrium and ventricle
   - **c** the right ventricle and left ventricle.

Monitoring the activity of the heart

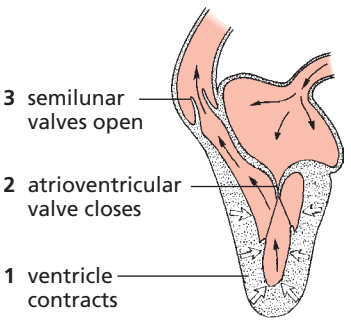
There are several ways by which the activity of the heart can be monitored. These include measuring **pulse** rate, listening to heart sounds and the use of **electrocardiograms (ECGs)**.

Pulse rate

You feel the ripple of pressure that passes down an artery as a result of the heart beat as a 'pulse' when the artery is near the surface of the body. You can feel the pulse in your radial artery by pressing the fingertips of one hand on the wrist of the other (Figure 11.7). It is important that the thumb is *not* used because it has its own pulse. There is also a noticeable pulse in the carotid artery in your neck. Digital pulse rate monitors are also available. These can be used on a finger, wrist or earlobe depending on the type. They give a very accurate reading.

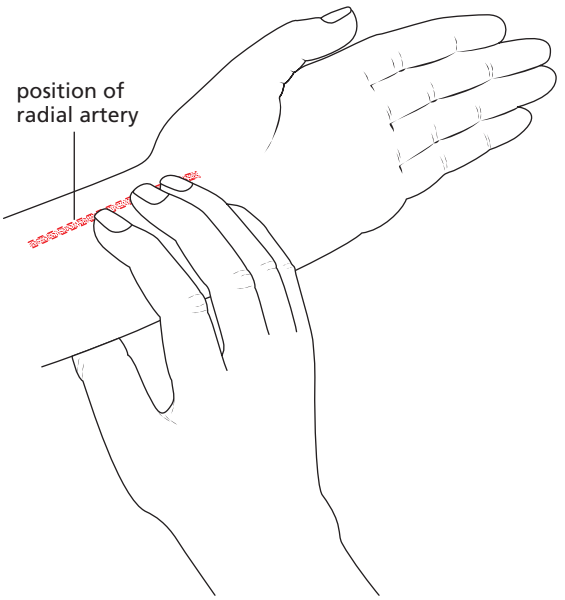


(a) ventricle filling



(b) ventricle emptying

▲ **Figure 11.6** Diagram of heartbeat (only the left side is shown)



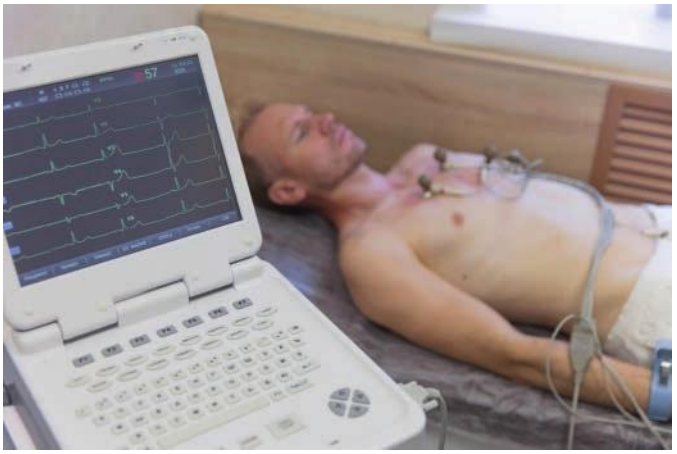
▲ **Figure 11.7** Taking the pulse

Heart sounds

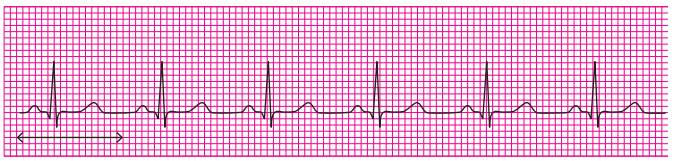
These can be heard using a stethoscope. This instrument amplifies the sounds of the heart valves opening and closing. A healthy heart produces a regular 'lub-dub' sound. The first ('lub') sound is caused by the closure of the atrioventricular valves separating the atria from the ventricles. The second ('dub') sound is caused by the closure of the semilunar valves at the entrance of the pulmonary artery and aorta. Observation of irregular sounds may identify an irregular heartbeat. If the 'lub' or 'dub' sounds are not clear, then this may be because of faulty valves.

ECGs

To obtain an ECG (electrocardiogram), electrodes, attached to an ECG recording machine, are stuck onto the skin on the arms, legs and chest (Figure 11.8). Electrical activity to do with heartbeat is then monitored and viewed on a computer screen or printed out (Figure 11.9). Any unusual patterns on the trace can be used to identify heart problems.



▲ **Figure 11.8** A patient undergoing an ECG



▲ **Figure 11.9** ECG trace

The effect of physical activity on the heart rate

A heartbeat is a contraction. Each contraction squeezes blood to the lungs and body. The pulse is a pressure wave passing through the arteries as a result of the heartbeat. At rest, the heart beats about 70 times a minute, but this varies according to a person's age, gender and fitness. It is higher if you are younger and/or female, and lower if you are fit. An increase in physical activity increases the pulse rate, which can rise to 200 beats per minute.

Why physical activity affects the heart rate

This is because during exercise the muscles need more energy, so the heart has to deliver more oxygen and glucose for respiration. After exercise has stopped, the pulse rate gradually drops to its resting state. If the individual is fit, this happens quickly, but an unfit person's pulse rate will take longer to return to normal.

Practical work

Safety

- Take care – participation should be voluntary. Students who do not wish to should not be forced to take part for any reason.

2 Investigating the effect of exercise on pulse rate

- Find your pulse in your wrist or neck – see Figure 11.7.
- Count the number of beats in 15 seconds, then multiply the result by four to work out a pulse rate in beats per minute. This is your resting pulse rate.
- Repeat the process two more times and then calculate an average resting pulse rate. This is to make your data more reliable, as one result may not be typical. If two readings for the same measurement (in this case, resting pulse rate) show too much variation, you should take extra readings and discount any outliers (readings that are abnormal).
- Carry out 2 minutes of exercise, for example, running on the spot. Then sit down and immediately start a stopwatch and measure your pulse rate over 15 seconds as before.
- Allow the stopwatch to keep timing. Measure your pulse rate every minute for 10 minutes.
- Convert all the readings to beats per minute. Plot a graph of pulse rate after exercise against time, with the first reading being 0 minutes.
- Finally, draw a horizontal line across the graph representing your average resting pulse rate.

Result

The pulse rate immediately after exercise should be much higher than the average resting pulse rate. With time the pulse rate gradually falls back to the average resting pulse rate.

Interpretation

During exercise the muscles need more oxygen and glucose for aerobic respiration to provide the energy needed for the increased movement. The heart rate increases to provide these materials. After exercise, demand for oxygen and glucose drops, so the pulse rate gradually returns to normal.

Practical work question

2 The data in the tables was collected by a student investigating the effect of exercise on pulse rate. The student measured his pulse at rest for 15 seconds and took three readings, which are recorded in Table 1. These were converted into the pulse rate in beats per minute. The mean resting pulse rate was calculated.

The student exercised for two minutes, then stopped exercising and began recording his pulse rate every minute for ten minutes. The results are in Table 11.2.

▼ **Table 11.1**

reading	pulse rate/beats in 15 seconds	pulse rate/beats min^{-1}	mean resting pulse rate/ beats min^{-1}
1	19		
2	20		
3	18		

▼ **Table 11.2**

time/min	pulse rate/beats min^{-1}
0	180
1	164
2	132
3	112
4	92
5	80
6	72
7	68
8	76
9	76
10	76

a Copy and complete Table 11.1 by
- **i)** calculating the resting pulse rates in beats per minute
- **ii)** calculating the mean resting pulse rate.

b Explain why it was important to take three readings.

c **i)** Use the data in Table 11.2 to plot a graph of pulse rate after exercise against time.
- **ii)** On your graph draw a horizontal line to represent the resting pulse rate and label the line.

d **i)** Use your graph to find how many minutes it took for the pulse rate to return to normal for the first time.
- **ii)** Suggest how the graph would be different if another, less fit, male student collected data for the same investigation.

Going further

Blood circulation in the fetus

The septum separating the left and right heart chambers stops the oxygenated blood in the left chambers from mixing with the deoxygenated blood in the right chambers. When a **fetus** is developing, there is a hole (the foramen ovale) between the right atrium and the left atrium, allowing blood to bypass the lungs. This is because the fetal blood is oxygenated by the **placenta** rather than the lungs. During the birth sequence, the foramen ovale closes, so all blood in the right atrium passes into the right ventricle and on to the lungs for oxygenation. Sometimes, the foramen ovale does not seal completely and the baby suffers from a *hole in the heart*. Babies with this condition tend to look blue

because their blood is not being oxygenated enough: some of it bypasses the lungs.

Control of the heartbeat

Heart muscle has a natural rhythmic contraction of its own, about 40 contractions per minute. However, it is supplied by nerves. These maintain a faster rate that can be adjusted to how much oxygen the body needs. At rest, the normal heart rate is about 70 beats per minute, but varies according to age, sex and other factors. During exercise, the rate may increase to 200 beats per minute.

The heart beat is started by the 'pacemaker', a small group of specialised muscle cells at the top of the right atrium. The pacemaker is linked to two sets of nerves from the brain. One group of nerves speeds up the heart rate and the other group slows it down. These nerves start at a centre in the brain that receives an input from **receptors** (See 'Nervous control in humans' in Chapter 14) in the circulatory system that are sensitive to blood pressure and levels of oxygen and carbon dioxide in the blood.

If blood pressure rises, nervous impulses reduce the heart rate. A fall in blood pressure causes a rise in the heart rate. Reduced oxygen concentration or increased carbon dioxide in the blood also contributes to a faster heart rate. This way, the heart rate is adjusted to meet the needs of the body at times of rest, activity and excitement.

The hormone **adrenaline** (see 'Hormones' in Chapter 14) also affects the heart rate. In conditions of excitement, activity or stress, adrenaline is released from the **adrenal glands** into the blood circulation. On reaching the heart it causes an increase in the rate and strength of the heartbeat.

Test yourself

3 Starting from the left atrium, put the following in the correct order for circulation of the blood: left atrium, vena cava, aorta, lungs, pulmonary artery, right atrium, pulmonary vein, right ventricle, left ventricle

4 Put the following in the correct order:
- **a** blood enters arteries
- **b** ventricles contract
- **c** atria contract
- **d** ventricles relax
- **e** blood enters ventricles
- **f** semilunar valves close
- **g** atrioventricular valves close.

5 Why is it incorrect to say 'all arteries carry oxygenated blood and all veins carry deoxygenated blood'?

6 State which parts of the heart
- **a** pump blood into the arteries
- **b** stop blood flowing the wrong way.

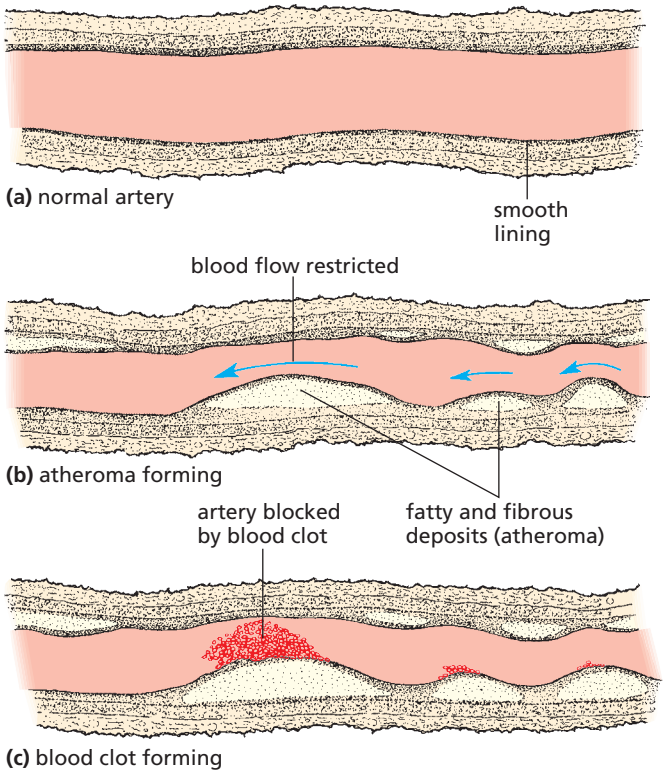
7 Explain why
- **a** the walls of the ventricles are more muscular than the walls of the atria
- **b** the muscle of the left ventricle is thicker than that of the right ventricle. (Hint: look at Figure 11.17)

Coronary heart disease

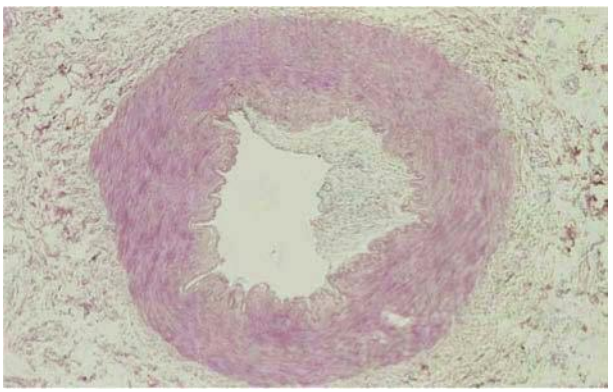
Deposits of a fatty substance, called atheroma, are laid down in patches in the lining of the large and medium arteries. This happens to everyone and the number and size of the patches increase with age. However, until one of them blocks an important artery the effects are not noticed. The patches may join up to make a bigger area, which reduces the internal diameter of the vessel (Figure 11.10).

The surface of a patch of fatty deposit can become rough, causing a blood clot to form. The **coronary artery** (Figure 11.2) supplies the muscles of the ventricles with blood. If this gets blocked it starves the muscles of oxygenated blood and the heart may stop beating. This is a severe heart attack. A blood clot might form anywhere in the arterial system. However, its effects in the coronary artery and in parts of the brain (strokes) are the most severe.

In the early stages of coronary heart disease, the atheroma may partially block the coronary artery and reduce the blood supply to the heart (Figures 11.10 and 11.11). This can lead to a pain in the chest that happens during exercise or hard work. This is a warning to the person that he or she is at risk and should take safety measures to avoid a heart attack.



▲ **Figure 11.10** Atheroma and blood clot formation



▲ **Figure 11.11** Atheroma partially blocking the coronary artery

Possible risk factors of coronary heart disease

Atheroma and blood clot formation are the direct causes of a heart attack. However, scientists are less certain about the long-term causes of coronary heart disease.

Increased risk of the disease can be inherited, but rates of the disease have increased a lot in industrial countries recently. This suggests that some features of diets or lifestyles in those countries might cause it. The main risk factors include an unbalanced diet with too much fat, stress, smoking, genetics, age, gender and a sedentary lifestyle.

Diet

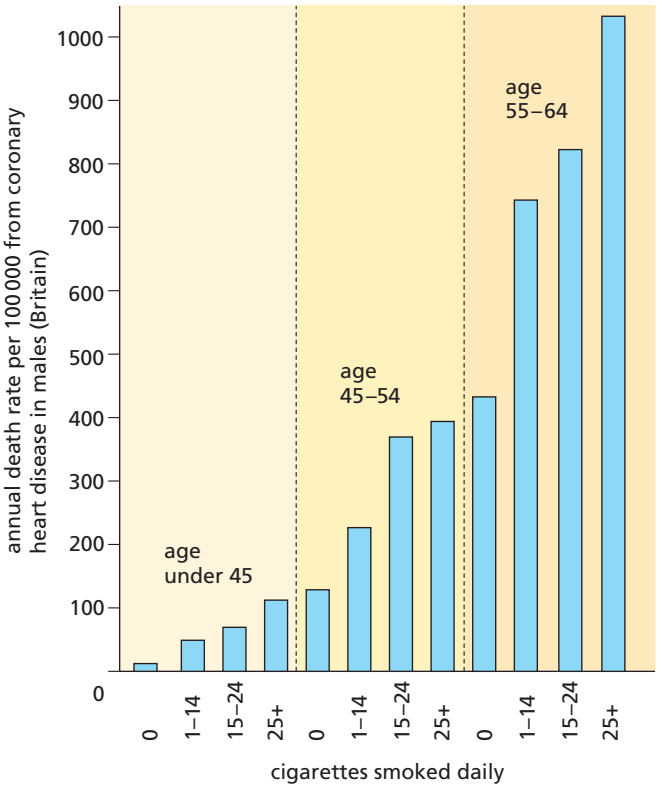
An unbalanced diet with too much animal fat and too many calories can lead to obesity. Being overweight puts extra strain on the heart and makes it more difficult for the person to exercise. Sometimes fats can form a deposit in arteries, restricting the flow of blood through them. The deposits can also cause blood clots, which can result in a heart attack.

Stress

Emotional stress often leads to raised blood pressure. High blood pressure may increase the rate at which atheroma are formed in the arteries.

Smoking

Statistical studies suggest that smokers are two to three times more likely to die from a heart attack than non-smokers of a similar age (Figure 11.12). The carbon monoxide and other chemicals in cigarette smoke may damage the lining of the arteries, allowing atheroma to form.



▲ **Figure 11.12** Smoking and heart disease. As you get older you are more likely to die from a heart attack. However, you can see that, in any age group, the more you smoke the higher your chances are of dying from heart disease

Genetics

Coronary heart disease appears to be passed from one generation to the next in some families. This is something we have no control over, but we can be aware of this risk and reduce some of the other risk factors to offset it.

Age and gender

As we get older our risk of suffering from coronary heart disease increases. Males are more at risk of a heart attack than females. It may be that males tend to have less healthy lifestyles than females. The hormone **oestrogen** offers females some protection from heart disease until later in life, when oestrogen levels drop.

Sedentary lifestyle

Heart muscle loses its tone and becomes less efficient at pumping blood when we do not exercise. Lack of exercise results in slower blood flow. This may allow atheroma to form in the arterial lining, although there is not much direct evidence for this.

Prevention of coronary heart disease

A person has less chance of becoming obese if they keep to a healthy, balanced diet. There will also be a low intake of animal fats, so this reduces the chances of atheroma and thrombus formation.

There is some evidence that regular, vigorous exercise reduces the chances of a heart attack. This may be because it increases muscle tone of skeletal muscle and cardiac muscle. Good heart muscle tone leads to an improved coronary blood flow, and so the heart does not have to work so hard to keep pumping.

Going further

Cholesterol and coronary heart disease

The fatty deposits that can develop in arteries contain cholesterol, which is present in the blood, combined with fats and proteins. Cholesterol is a very important chemical in the body because it is needed to make cell membranes. However, people with high blood cholesterol levels are more likely to suffer from heart attacks than people with low cholesterol levels. Blood cholesterol levels can be affected by the amount and type of fat in the diet. Many doctors and dieticians believe that saturated animal fats (milk, cream, butter, cheese, egg-yolk, fatty meat) are more likely to raise the blood cholesterol than vegetable oils. These contain mainly unsaturated fatty acids.

Going further

Correlation and cause

It is not possible or suitable to carry out experiments on humans to find out more details of the causes of heart attacks. The evidence must be collected from long-term studies on groups within populations, for example, smokers and non-smokers. Statistical analysis of these studies will often show a correlation, for example, more smokers, in the same age group, suffer heart attacks than non-smokers. This correlation does not prove that smoking causes heart attacks. It may be that people who are already prone to heart attacks for other reasons (e.g. high blood pressure) are more likely to take up smoking. This may seem unlikely, but, the correlation cannot be used to claim a cause and effect until scientists can show that substances in tobacco smoke do cause an increase in atheroma.

However, there are so many other correlations between smoking and ill-health (e.g. bronchitis, emphysema, lung cancer) that the indirect evidence against smoking is very strong.

Another example of a positive correlation is between having a television set and heart disease. Nobody would seriously claim that television sets cause heart attacks. The correlation is probably linked to a wealthy lifestyle, to do with over-eating, fatty diets, lack of exercise and other factors that may contribute to coronary heart disease.

Test yourself

8 In order to reduce your risk of coronary heart disease in later life, state
   a what positive steps you could take
   b what things you should avoid.

9 State which factors, which contribute to the risk of coronary heart disease, we have no control over.

Blood vessels

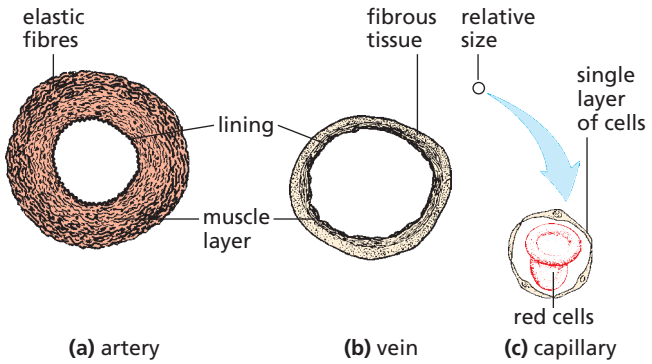
FOCUS POINTS

- ★ What is the structure of arteries, veins and capillaries?
- ★ How is the structure of arteries, veins and capillaries related to the pressure of the blood that they transport?
- ★ Where in the body are the main blood vessels to and from the heart, lungs, liver and kidneys?

Arteries

Arteries are vessels (Figure 11.13) that carry blood *from* the heart to the limbs and organs of the body (Figure 11.17). The blood in the arteries is oxygenated except for the pulmonary arteries.

Arteries have a narrower **lumen** than veins and more elastic tissue and muscle fibres in their thick walls. The thick muscular walls can withstand the high pressure of the blood they transport.



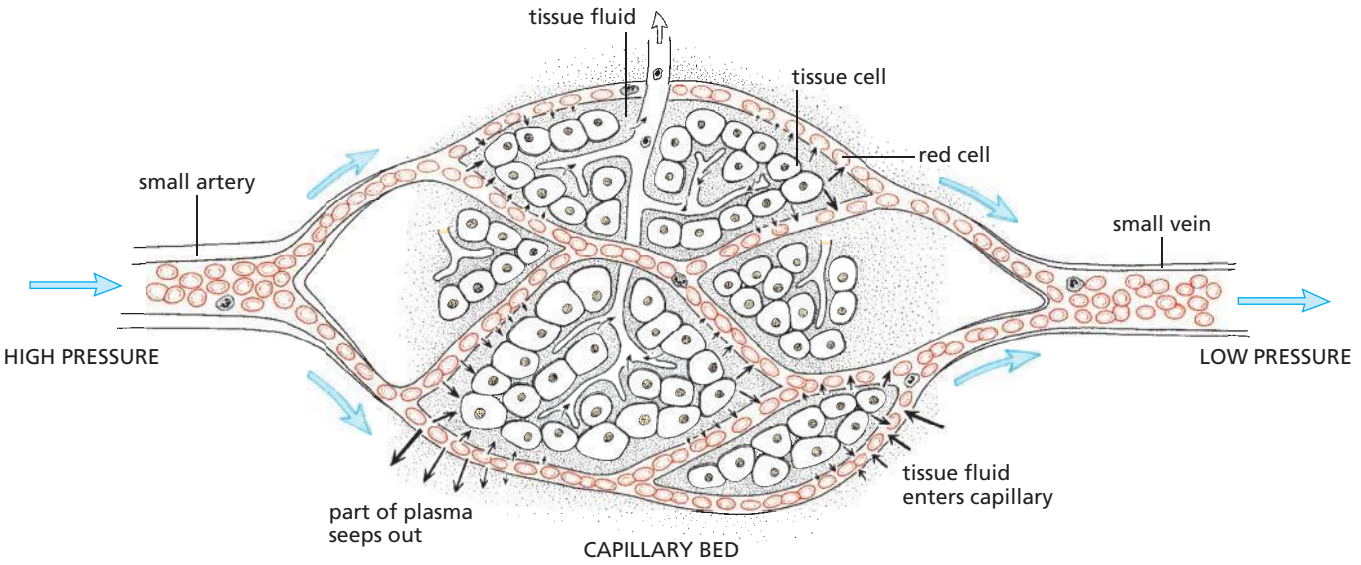
▲ **Figure 11.13** Blood vessels, transverse section

The arteries divide many times to form a branching network of microscopic vessels passing between the cells of every living tissue (Figure 11.14). These final branches are called capillaries.

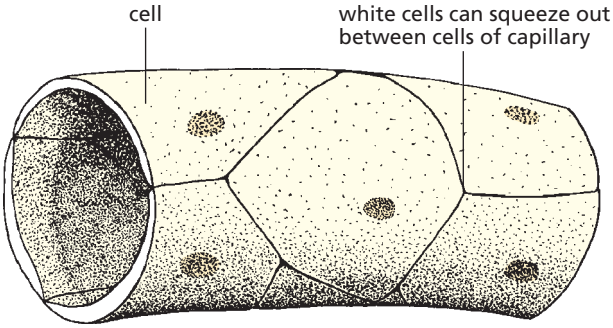
Capillaries

These are tiny vessels, often only 0.001 mm in diameter and with walls only one cell thick (Figures 11.13(c) and 11.14). Capillaries have a very narrow lumen, no valves and no muscle or elastic in their walls. Although all the components of the blood cannot escape from the capillary, the thin capillary walls allow some liquid to pass through, i.e. they are permeable. Blood pressure in the capillaries forces part of the plasma out through the walls.

The capillary network is so dense that no living cell is far from a supply of oxygen and food. The capillaries join up into larger vessels, which then combine to form veins.



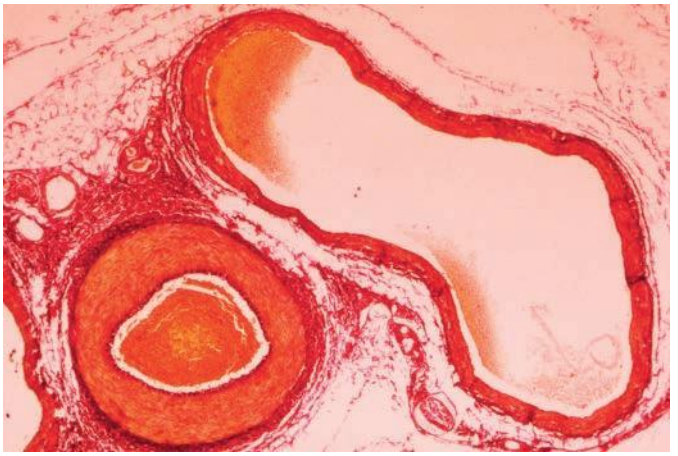
▲ **Figure 11.14** Relationship between capillaries and cells. The slow flow rate in the capillaries allows plenty of time for the exchange of oxygen, food, carbon dioxide and waste products



▲ **Figure 11.15** Diagram of blood capillary

Veins

Veins return blood from the tissues to the heart (Figure 11.17). The blood pressure in them is steady and is less than that in the arteries. They have a wider lumen and their walls are thinner, less elastic and less muscular than those of the arteries (Figures 11.13(b) and 11.16). They also have valves in them, which are like the semilunar valves (Figure 11.4, page 166).

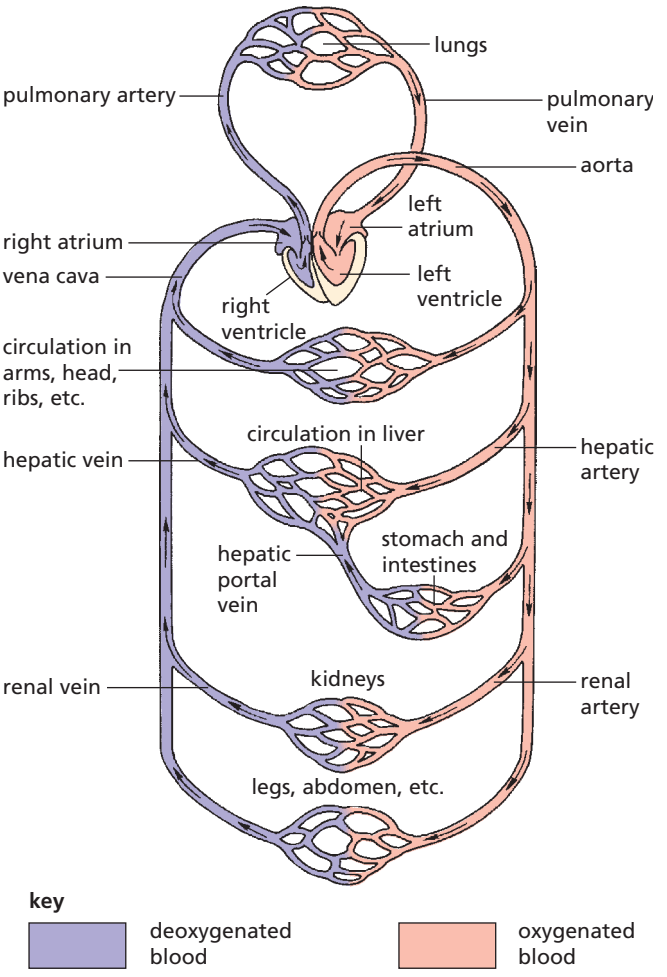


▲ **Figure 11.16** Transverse section through a vein and artery. The vein is on the right, the artery on the left. Notice that the wall of the artery is much thicker than that of the vein. The material filling the artery is formed from coagulated red blood cells (cells which have stuck together). These are also visible in two areas of the vein

The blood in most veins is deoxygenated and contains less nutrients but more carbon dioxide than the blood in most arteries. This is because respiring cells have used the oxygen and nutrients and produced carbon dioxide (Figure 11.23). The pulmonary veins, which return blood from the lungs to the heart, are an exception. They contain oxygenated blood and a reduced level of carbon dioxide.

The main blood vessels related to the heart, lungs, liver and kidneys are shown in Figure 11.17. The right atrium of the heart is supplied with blood by the vena cava (the main vein of the body). The right ventricle sends blood to the lungs along the pulmonary artery. The left atrium of the heart receives blood from the lungs in the pulmonary vein and the right ventricle sends it to the body in the aorta, the main artery (see Chapter 9). There are two pulmonary arteries and two pulmonary veins, because there are two lungs. There are also two vena cavae: one returns blood from the lower body; the other from the upper body. Each kidney receives blood from a **renal artery**. When the blood has been filtered it is returned to the vena cava through a **renal vein** (see Chapter 13).

The liver receives blood from two vessels: the **hepatic artery** and the hepatic portal vein. The hepatic artery carries oxygenated blood and the hepatic portal vein transfers blood that is rich in digested food molecules from the stomach and intestines. The **hepatic vein** returns blood from the liver to the vena cava.



▲ **Figure 11.17** Diagram of human circulation

Going further

Blood pressure

The heart pumps to produce a pressure that drives blood around the circulatory system (Figure 11.17). In the arteries the pressure varies with the heartbeat, and you can feel the pressure wave as a pulse. The millions of tiny capillaries slow down the blood flow. By the time the blood enters the veins, the peaks in blood pressure due to the heartbeat are lost and the blood pressure has dropped.

Although blood pressure varies with age and activity, it is normally kept within narrow limits by **negative feedback** (see 'Homeostasis' in Chapter 14). The filtration process in the kidneys (Chapter 13) needs a steady blood pressure. If blood pressure falls too much because, for example, of loss of blood or shock, then the kidneys may stop working. There is an increased risk of heart disease or stroke if the blood pressure is consistently higher than normal.

Table 11.3 compares the structure of arteries, veins and capillaries and explains how their structures are related to their functions.

▼ **Table 11.3** Comparing arteries, veins and capillaries

Blood vessel	Structure	Explanation of how structure is related to function
artery	thick, tough wall with muscles, elastic fibres and fibrous tissue	Carries blood at high pressure – prevents bursting and maintains pressure wave. The large arteries, near the heart, have a greater proportion of elastic tissue, which allows these vessels to withstand the surges of high pressure caused by the heartbeat.
	lumen quite narrow, but increases as a pulse of blood passes through	This helps to maintain blood pressure.
	valves absent	High pressure prevents blood flowing backwards.
vein	thin wall – mainly fibrous tissue with little muscle or elastic fibres	Carries blood at low pressure.
	lumen large	To reduce resistance to blood flow.
	valves present	To prevent back-flow of blood. Contraction of body muscles, particularly in the limbs, squeezes the thin-walled veins. The valves in the veins prevent the blood flowing backwards when the vessels are squeezed in this way. This helps the return of venous blood to the heart.
capillary	permeable wall, one cell thick, with no muscle or elastic tissue	This allows diffusion of materials between the capillary and surrounding tissues.
	lumen approximately one red blood cell wide	White blood cells can squeeze between cells of the wall. Blood cells pass along the capillary slowly to allow diffusion of materials and tissue fluid.
	valves absent	Blood is still under pressure.

Test yourself

10 State which important veins are not labelled in Figure 11.2.

11 Describe how veins differ from arteries in
- **a** their function
- **b** their structure.

12 Explain how the structure of capillaries is related to their function.

Blood

FOCUS POINTS

- ★ What are the components of blood?
- ★ What do red blood cells look like in photomicrographs and diagrams?
- ★ What do lymphocytes and phagocytes look like in photomicrographs and diagrams?
- ★ What are the functions of the components of blood?
- ★ What are the roles of blood clotting?
- ★ What is the process of clotting?

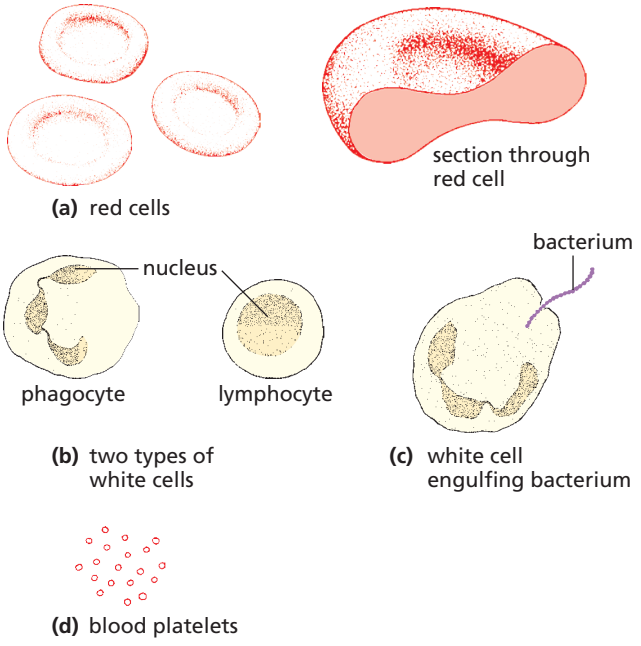
Blood consists of red blood cells, white blood cells and **platelets** floating in a liquid called plasma. There are between 5 and 6 litres of blood in the body of an adult, and each cubic centimetre contains about 5 billion red blood cells.

Red blood cells

These are tiny, disc-like cells (Figures 11.18(a) and 11.20) which do not have nuclei. They are made of spongy cytoplasm surrounded by an elastic cell membrane. Their cytoplasm contains the red pigment haemoglobin, a protein combined with iron. In places where there is a high concentration of oxygen, haemoglobin combines with oxygen. Oxygen is released in places where the oxygen concentration is low (Figure 11.19). This makes haemoglobin very useful in carrying oxygen from the lungs to the tissues.

Blood that contains mainly oxyhaemoglobin is oxygenated. Blood with little oxyhaemoglobin is deoxygenated.

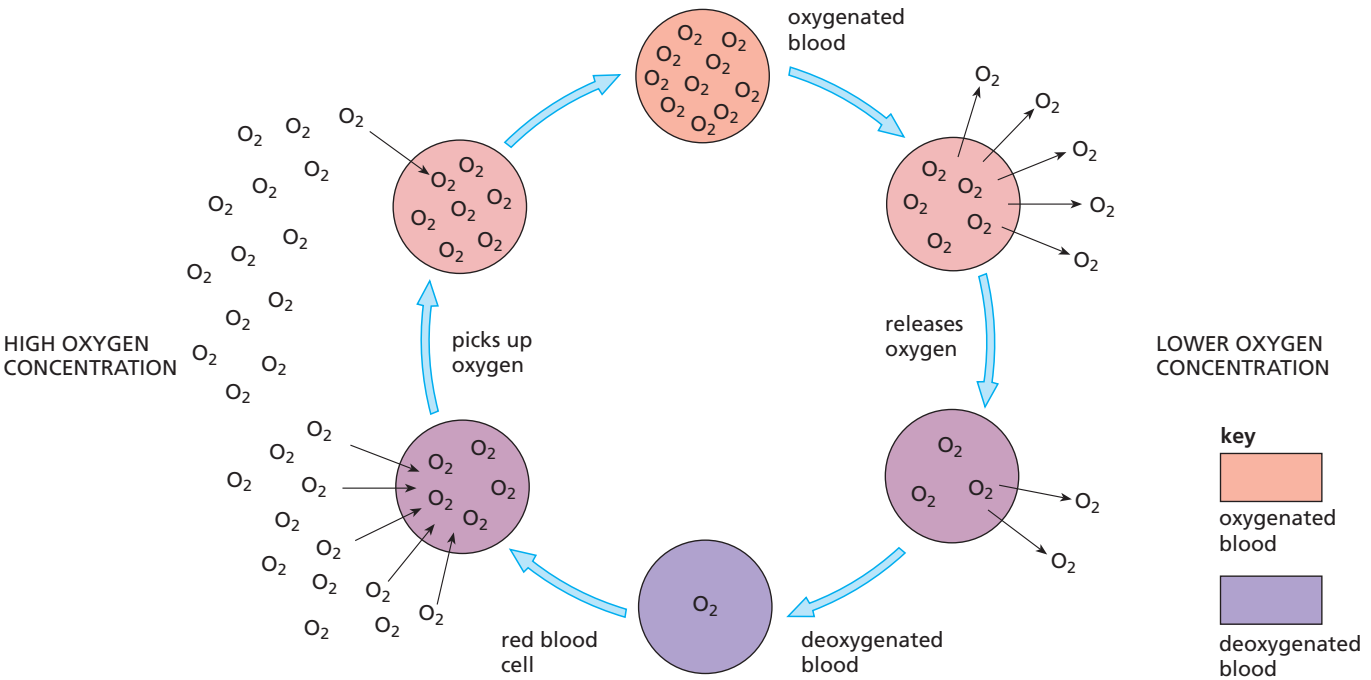
Each red blood cell lives for about 4 months. Then it breaks down. The iron from the haemoglobin is stored in the liver. About 200 000 million red blood cells wear out and are replaced each day. This is about 1% of the total. Red blood cells are made by the red bone marrow of some of the bones in the skeleton – in the ribs, vertebrae and sternum, for example.



▲ **Figure 11.18** Blood cells

White blood cells

There are several different kinds of white blood cell (Figures 11.18(b) and 11.20). Most are larger than the red blood cells and they all have a nucleus.



▲ **Figure 11.19** The function of the red blood cells

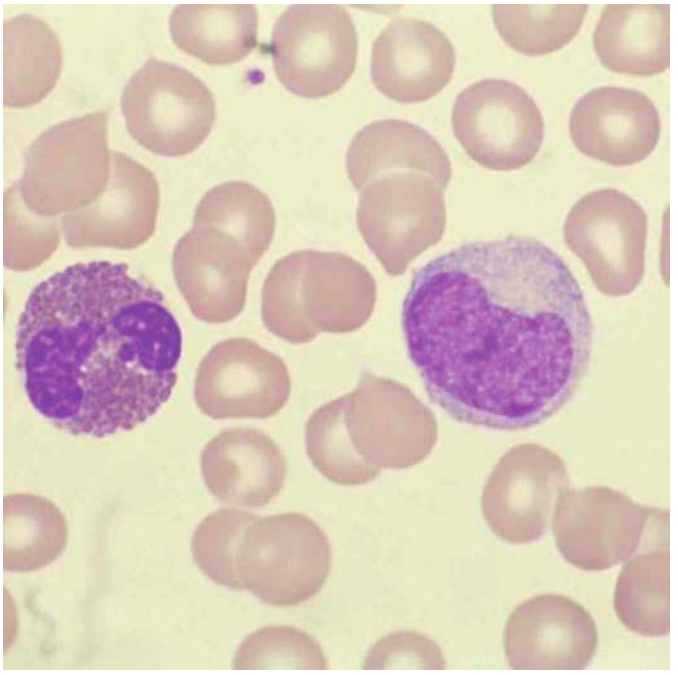
There is one white blood cell to every 600 red blood cells, and they are made in the same bone marrow that makes red blood cells.

The two most numerous types of white blood cells are **phagocytes** and **lymphocytes**.

The phagocytes can move about by a flowing action of their cytoplasm and can escape from the blood capillaries into the tissues by squeezing between the cells of the capillary walls. They collect at the site of an infection, engulfing and digesting harmful bacteria and cell debris – a process called **phagocytosis** (Figure 11.18(c)). In this way they prevent the spread of infection through the body. One of the functions of lymphocytes is to produce **antibodies**.

Platelets

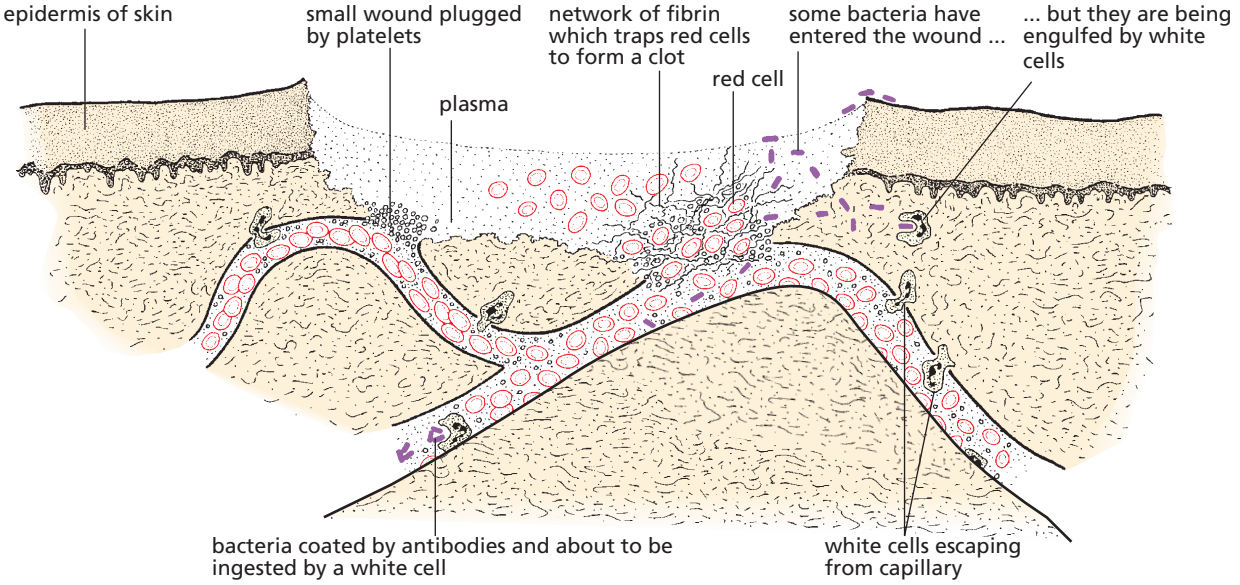
These are pieces of special blood cells formed in the red bone marrow. Platelets help to clot the blood at wounds, and so stop the bleeding and prevent pathogens entering the body.



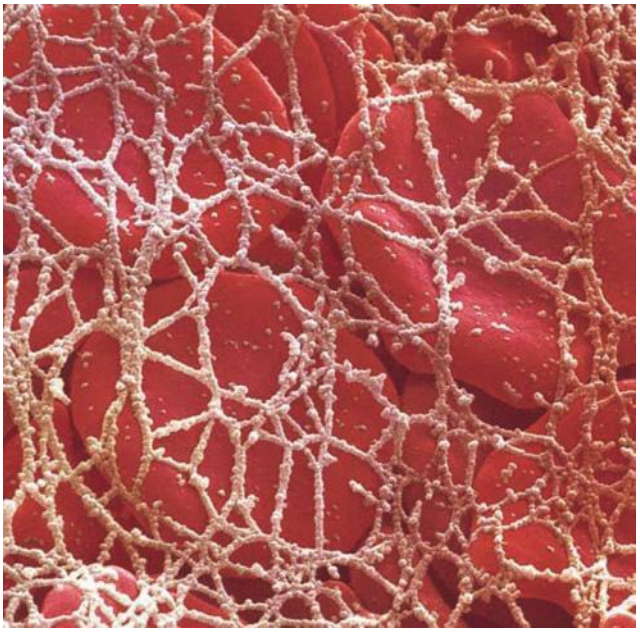
▲ **Figure 11.20** Red and white blood cells from human blood (×2500). The large nucleus can be seen clearly in the white blood cells

Clotting

When tissues are damaged and blood vessels cut, **platelets** clump together and block the smaller capillaries. The platelets and damaged cells at the wound also produce a substance that acts, through a series of enzymes, on the soluble plasma protein called **fibrinogen**. As a result of this action, the fibrinogen is changed into insoluble **fibrin**, which forms a network of fibres across the wound. Red blood cells become trapped in this network and so form a blood clot. The clot not only stops further loss of blood, but also prevents the entry of harmful bacteria into the wound (Figures 11.21 and 11.22).



▲ **Figure 11.21** The defence against infection by pathogens. An area of skin has been damaged and two capillaries broken open



▲ **Figure 11.22** Red blood cells trapped in a fibrin network (×6 500)

Worked example

You will recall that Magnification = $\frac{\text{image size}}{\text{actual size of the specimen}}$

So, actual size = $\frac{\text{image size}}{\text{magnification}}$

The diameter of the largest cell is 25 mm. Convert this into micrometres by multiplying it by 1 000. So, its diameter is 25 × 1 000 = 25 000 μm

The magnification is 2 500.

Therefore, the actual size = 25 000 ÷ 2 500 = 10 μm.

Task

1 What is the diameter of the largest cell in millimetres?

Write your answer in standard form.

Practical work

3 Drawing and measuring blood cells

- Study the photomicrograph of blood cells in Figure 11.20.
- Identify the three types of blood cells present.
- Make a labelled diagram of one of each of the cells.
- The photomicrograph has a magnification of ×2 500. Measure the diameter of the largest cell and calculate its actual size (see worked example).

Tips for a good drawing:

- Use a sharp HB pencil.
- Make each of your drawings large (at least one-quarter of an A4 sheet of paper).
- Draw the outline first, to get the dimensions of the image correct, then add details you can see.
- Use clean, unbroken lines.
- Avoid shading or using colour.
- Labels should be written horizontally outside the drawing.
- Link each label to the part with a ruled pencil line, touching the part it is labelling.
- The label lines should never cross each other.
- Give the drawing a title (in this case, the type of cell).
- Add a magnification to the drawing. This will be an estimation. How many times bigger than the image is your drawing? Multiply this by the photomicrograph magnification (×2 500).

Practical work question

3 A red blood cell has a diameter of 8 μm. Its mean thickness is 1.5 μm.
Estimate the surface area of the cell.

Plasma

The liquid part of the blood is called plasma. It transports the blood cells round the body. Plasma is water with many substances dissolved in it. For example, the ions of sodium, potassium, calcium, chloride and hydrogen carbonate are present. The plasma will also contain varying amounts of nutrients like amino acids, glucose, vitamins, plasma proteins and lipids. There may also be hormones (Chapter 14) present, depending on the activities taking place in the body. The excretory products, urea and carbon dioxide, are dissolved in the plasma.

The liver and kidneys keep the composition of the plasma steady, but the amount of digested food, salts and water will vary according to food intake and body activities.

Table 11.4 summarises the role of transport by the blood system.

▼ **Table 11.4** Transport by the blood system

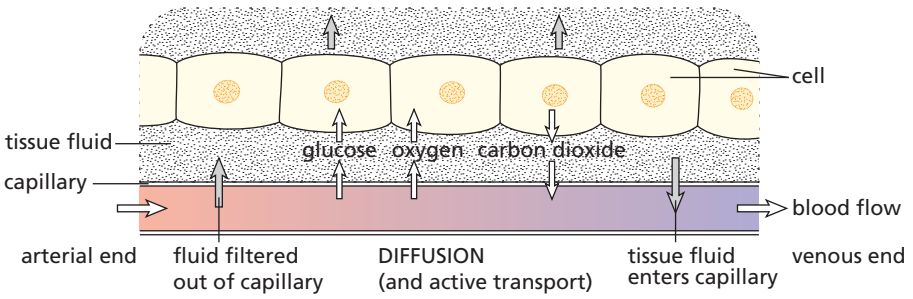
Substance	From	To
oxygen	lungs	whole body
carbon dioxide	whole body	lungs
urea	liver	kidneys
hormones	glands	target organs
digested food	intestine	whole body
heat	abdomen and muscles	whole body

Note: The blood is not directed to a single organ. For example, a molecule of urea may go around the circulation many times before, by chance, it enters the renal artery and is removed by the kidneys.

Going further

The transfer of materials between capillaries and tissue fluid and body cells

The fluid that escapes from capillaries is not blood, nor plasma, but tissue fluid. Tissue fluid is like plasma but contains less protein, because protein molecules are too large to pass through the walls of the capillaries. This fluid bathes all the living cells of the body. As it contains dissolved food and oxygen from the blood, it supplies the cells with their needs (Figures 11.14 and 11.23). Some of the tissue fluid eventually leaks back into the capillaries, having passed on its oxygen and dissolved food to the cells. However, it has now received the waste products of the cells, like carbon dioxide, which are carried away by the bloodstream.



▲ **Figure 11.23** Blood and tissue fluid

Test yourself

13 Compare in what ways white blood cells are different from red blood cells in
   a their structure
   b their function.

14 a Suggest where in the body you would expect
   i) haemoglobin to be combining with oxygen to form oxyhaemoglobin
   ii) oxyhaemoglobin to be breaking down to oxygen and haemoglobin.
   b Suggest why it is important for oxyhaemoglobin to be an unstable compound, i.e. easily changed to oxygen and haemoglobin.
   c What might be the effect on a person whose diet contained too little iron?

15 A student cuts her skin.
   a Describe how a clot forms in the cut.
   b Explain why it is important that a clot forms in the cut.

Going further

Ideas about the circulatory system

There must have been knowledge of human internal anatomy thousands of years ago. This might have come, for example, from the practice of removing internal organs before the process of mummification in Ancient Egypt. However, there seems to have been little or no systematic study of human anatomy in the sense that the parts were named, described or illustrated.

Some of the earliest records of anatomical study come from the Greek physician, Galen.

Galen (AD130–200)

Galen dissected goats, monkeys and other animals and produced detailed and accurate records. He was not allowed to dissect human bodies, so his descriptions did not always relate to human anatomy.

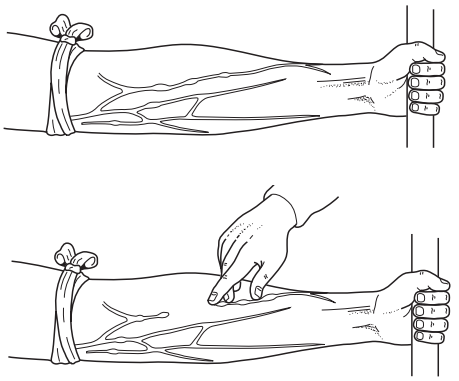
The anatomical knowledge was important, but the functions of the various parts could only be guessed at. It was known that the veins contained blood but when an organism dies, the arteries are usually empty and it was assumed that they carried air or something described as *animal spirit*. Galen observed the pulse but thought that it was caused by surges of blood into the veins.

William Harvey (1578–1657)

In the 15th and 16th centuries, vague ideas about the movement of blood began to develop, but it was an English physician called William Harvey who produced evidence to support the circulation theory.

Harvey's forerunners had made informed guesses, but Harvey carried out experiments to support his ideas. He noted that the valves in the heart would only allow blood to pass in one direction. So the idea that blood moved backwards and forwards was false. When he limited the blood flow in an artery he observed that it swelled on the side nearest the heart. However, a vein swelled on the side away from the heart.

Figure 11.24 shows a simple experiment that shows the presence of valves in the veins and supports the idea of a one-way flow.



▲ **Figure 11.24** Harvey's demonstration of valves and one-way flow in a vein. The vein is pressed down, and the blood forced out by running a finger up the arm. The vein refills, but only as far as the valve. (Compare with Figure 11.4, page 166.)

Harvey published his results in 1628. They were at first rejected and mocked, not because anyone tried his experiments or tested his observations, but simply because his conclusions contradicted what Galen had written 1500 years before.

By 1654, Harvey's theory of circulation was widely accepted, but it was still not known how blood passed from the arteries to the veins. Harvey observed that arteries and veins branched and re-branched until the vessels were too small to be seen. He suggested that the connection was made through these tiny vessels. This was confirmed after the microscope had been invented in 1660 and the vessels were called capillaries.

The significance of this history is that, although it is reasonable to make an informed guess at the function of a structure or organ, it is only by testing these guesses by experiment that they can be supported or disproved.

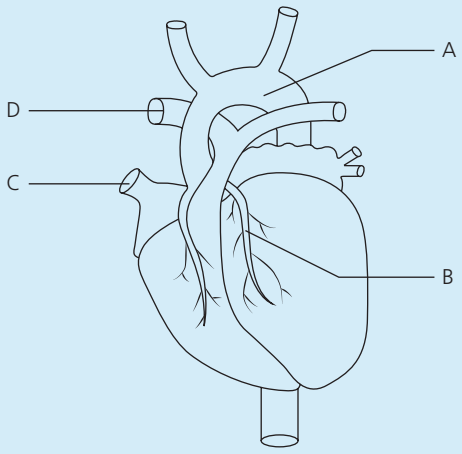
Revision checklist

After studying Chapter 11 you should know and understand the following:

- ✔ The circulatory system is made up of blood vessels with a heart and valves to ensure one-way flow of blood.
- ✔ Humans have a double circulation.
- ✔ The heart is a muscular pump with valves, which sends blood around the circulatory system.
- ✔ The left side of the heart pumps oxygenated blood around the body.
- ✔ The right side of the heart pumps deoxygenated blood to the lungs.
- ✔ The left and right sides of the heart are divided by a septum, keeping oxygenated and deoxygenated blood separate.
- ✔ The heart contains atrioventricular and semilunar valves, preventing back-flow of blood.
- ✔ The atria are thin walled and receive blood from veins.
- ✔ The ventricles have thick muscular walls to pump blood through arteries.
- ✔ Heart activity can be monitored by ECG, pulse rate and stethoscope, which transmits the sound of valves closing.
- ✔ Arteries carry blood from the heart to the tissues.
- ✔ Veins return blood to the heart from the tissues.
- ✔ Capillaries form a network of tiny vessels in all tissues and their features allow them to exchange material between the blood plasma and surrounding tissues.
- ✔ The main blood vessels to and from the heart are the aorta and vena cava; to and from the lungs are the pulmonary artery and pulmonary vein; and to and from the kidneys are the renal artery and renal vein.
- ✔ The liver is supplied by the hepatic artery and hepatic portal vein.
- ✔ Blockage of the coronary arteries in the heart leads to a heart attack.
- ✔ Smoking, fatty diets, stress, lack of exercise, genetic disposition and age may contribute to heart disease.
- ✔ Blood consists of red blood cells, white blood cells and platelets suspended in plasma.
- ✔ Plasma transports blood cells, ions, soluble nutrients, for example, glucose, amino acids, vitamins, plasma proteins, hormones and carbon dioxide.
- ✔ The red blood cells carry oxygen. The white blood cells attack bacteria by phagocytosis and production of antibodies. Platelets are needed to clot blood.
- ✔ Lymphocytes and phagocytes have distinctive shapes and features.
- ✔ Antibodies are chemicals made by white blood cells in the blood. They attack any microorganisms or foreign proteins that get into the body.
- ✔ Blood clotting involves the conversion of the soluble blood protein fibrinogen to insoluble fibrin, which traps blood cells.
- ✔ Blood clotting prevents loss of blood and entry of pathogens into the body.

Exam-style questions

1 The diagram shows the external appearance of a human heart.



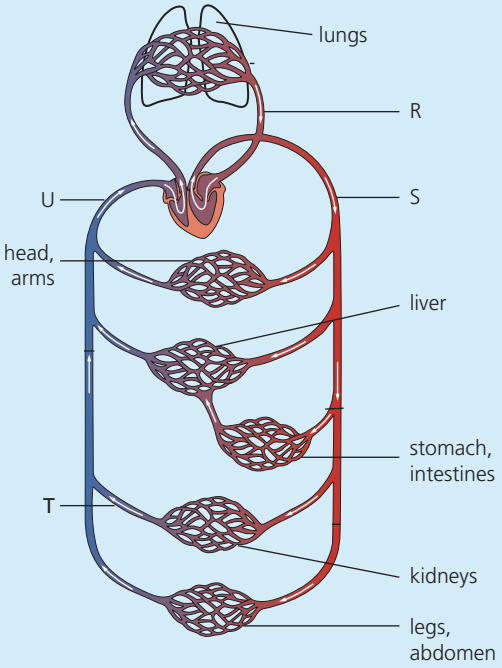
a Copy and complete the table to
i) identify the blood vessels A, B, C and D [4]
ii) place a tick (✓) or cross (×) to show if the blood in the vessel is oxygenated. [2]

vessel	name of vessel	blood in the vessel is oxygenated tick (✓) or cross (x)
A		
B		
C		
D		

b Blockage of the blood vessel B is the cause of coronary heart disease.
i) State **two** factors that increase the risk of this happening. [2]
ii) State **two** ways of reducing this risk. [2]
iii) Describe what happens to the heart when blood vessel B is blocked. [2]

2 **a** State **three** structural features that distinguish an artery from a vein. [3]
b Describe the functions of capillaries. [2]

3 Study the diagram of the circulatory system of a human.



a Identify the blood vessels labelled R, S, T and U. [4]
b State why there are two of the blood vessel T in the human body. [1]
c The blood vessel from the heart to the lungs is an artery. In what way is it different from other arteries? [1]

4 Suggest why a person whose heart valves are damaged by disease is unable to take part in active sport. [4]

5 Describe the relationship between the liver and the three blood vessels it is associated with. [6]

12 Disease and immunity

Focus

We live in a time where there have been important advances in our knowledge and understanding of infectious diseases. There are now effective safety measures and medicines. However, new infections continue to appear. The COVID-19 pandemic demonstrates how important it is to take suitable precautions to reduce the risk of catching the disease and stop its spread. Scientists have been vital in identifying the nature of the virus so that a **vaccine** can be made. In this chapter you will learn more about diseases, their treatment, our natural defences and ways our body can be stimulated to defend itself.

Pathogens and transmission

FOCUS POINTS

- ★ What is a pathogen?
- ★ What is a transmissible disease?
- ★ How are pathogens transmitted?
- ★ How are the following important in controlling the spread of disease: a clean water supply, hygienic food preparation, good personal hygiene, waste disposal, sewage treatment?
- ★ What is the role of the mosquito as a disease vector?
- ★ What is the cause of malaria and how is it controlled?
- ★ How can human immunodeficiency virus (HIV) be transmitted and what might it cause?
- ★ What is cholera?
- ★ How does the cholera bacterium cause disease?
- ★ What are the effects of excessive alcohol consumption?
- ★ What are the effects of tobacco smoke?

Key definitions

A **pathogen** is a disease-causing organism.

A **transmissible disease** is a disease in which the pathogen can be passed from one host to another.

Pathogens

Pathogens include many bacteria, viruses and some fungi, as well as several Protoctista and other organisms. Pathogenic bacteria may cause diseases because of the damage they do to the host's cells, but most bacteria also produce poisonous waste products called **toxins**. Toxins damage the cells in which the bacteria are growing. They also upset some of the systems in the body. This causes a raised temperature, headache, tiredness and weakness, and sometimes diarrhoea and vomiting. The toxin produced by the *Clostridium* bacteria (which causes tetanus) is so poisonous that as little as 0.000 23 g is fatal.

Many viruses cause diseases in plants and animals. Human virus diseases include those that cause the common cold, COVID-19, poliomyelitis, measles, mumps, chickenpox, herpes, rubella, influenza and **acquired immune deficiency syndrome (AIDS)**. Tobacco mosaic virus affects tomato plants as well as tobacco. It causes mottling and discoloration of the leaves, eventually stunting the growth of the plant.

While most fungi are feeding on dead organic matter (saprophytes), some are parasitic, obtaining their nutrients from living organisms. The hyphae of parasitic fungi penetrate the tissues of their host plant and digest the cells and their contents. If the mycelium spreads widely through the host, it usually causes the death of the plant. The bracket fungus shown in Chapter 2, Figure 2.33 on page 37, is the fruiting body of a mycelium that is spreading through the tree and will eventually kill it.

Worked example

Standard form is a way of writing down very large or very small numbers more easily. It uses the powers of 10 to show how big or how small the number is.

You write it as: $y \times 10^n$

- where y is always a number bigger or equal to 1, but less than 10
- and n can be any positive or negative whole number.

The magnification of the red and white blood cells in the last chapter (Figure 11.20) was ×2500.

Now, this number is much more than 1.

To convert the number into standard form, you need to separate the number into two parts – a number multiplied by a power of 10.

The number will be 2.5 (which is bigger than 1 but less than 10). To change the number to 2.5, the decimal point needs to be moved to the left three times. This means that the power is 10^3.

So, in standard form the magnification of the cells is 2.5×10^3.

In the last paragraph, on pathogens, I stated that as little 0.000 23 g of poison from *Clostridium* bacteria is fatal.

At the moment, this number is much less than 1.

To convert the number into standard form, you need to separate the number into two parts – a number multiplied by a power of 10.

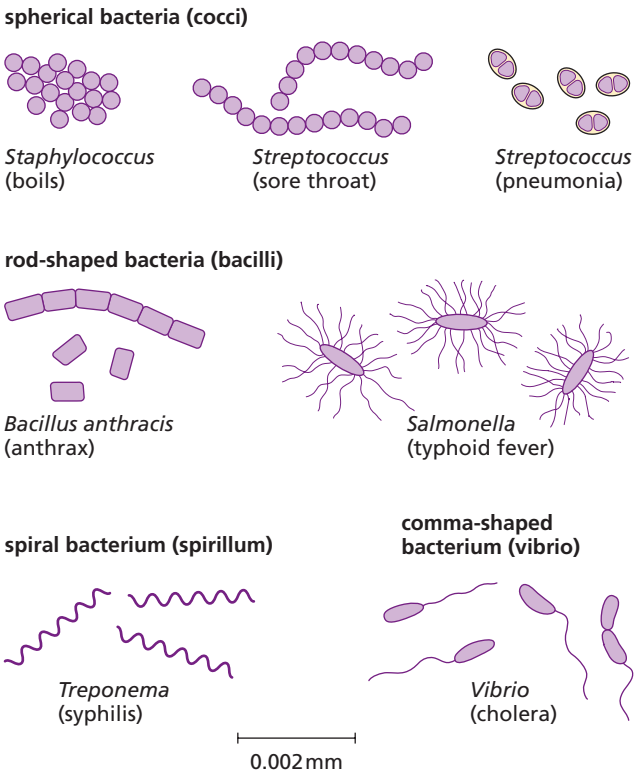
To convert 0.000 23 into standard form, the number will be 2.3, because this is more than 1 but less than 10.

To change the number to 2.3, the decimal point was moved to the right four times. This means that the power is 10^{-4}.

So, 0.000 23 in standard form is 2.3×10^{-4}.

Tasks

1 Change the number in Figure 12.1 to standard form.
2 Look for other examples of very large or very small numbers in the book and practice converting them into standard form. There are plenty in Chapter 2!



▲ **Figure 12.1** Some pathogenic bacteria

Fungus diseases like blight, rusts or mildews (see Chapter 2, Figure 2.34) cause large losses to farmers. Scientists are always searching for new varieties of crop plants that are **resistant** to fungus disease, and for new chemicals (fungicides) to kill parasitic fungi without harming the host.

A few parasitic fungi cause diseases in animals, including humans. One group of these fungi cause tinea or ringworm. The fungus grows in the epidermis of the skin and causes irritation and inflammation (swelling). One type of tinea is athlete's foot, in which the skin between the toes becomes infected. Tinea is very easily spread by contact with infected towels or clothing but can usually be cured quickly with a fungicidal ointment.

Transmission

Pathogens responsible for transmissible diseases can be spread either through direct contact or indirectly. The means of transmission is called the vector.

Direct contact

This may involve transfer through blood or other body fluids. **Human immunodeficiency virus (HIV)** is commonly passed on by infected drug addicts, who inject the drug into their bloodstream, if they share needles with other drug users. If one user

injects himself, the pathogens in his blood will contaminate the syringe needle. If a second drug user injects with the same needle, the pathogens are passed on. Anyone cleaning up dirty needles is at risk of infection if they accidently stab themselves. Surgeons carrying out operations need to be especially careful not to be in direct contact with the patient's blood. This could happen, for example, by cutting themselves while carrying out an operation. A person with HIV, or another sexually transmitted disease, who has unprotected sex can pass on the pathogen to their partner through body fluids. However, transfer by saliva is now considered to be a very low risk.

Indirect contact

This may involve infection from pathogens on contaminated surfaces, for example, during food preparation. Raw meat carries bacteria, which are killed if the meat is cooked enough. However, if the raw meat is prepared on a surface that is then used for other food preparation, like cutting up fruit or vegetables that are eaten raw later, then the pathogens from meat can be transferred to the fresh food. The person handling the food can also transmit disease if he or she does not wash their hands after using the toilet, moving rubbish or handling raw produce.

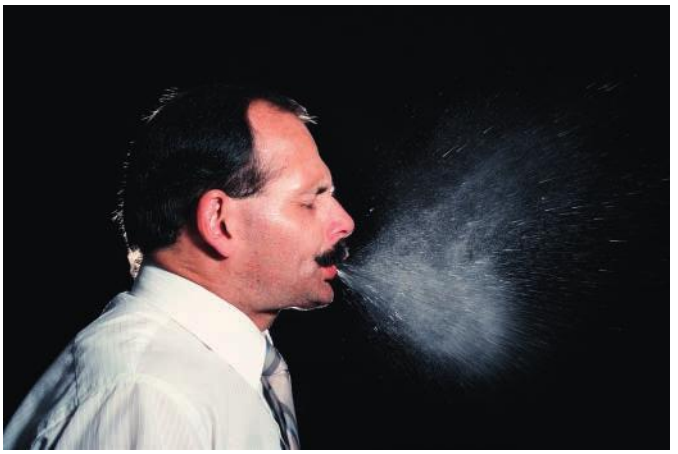
For example, in 2018 in southern India, at least 11 people died from suspected food poisoning and 130 others were ill after eating contaminated food during a ceremony. Several crows and dogs also died after eating scraps of the food.

Airborne, droplet or aerosol infection

When we sneeze, cough, laugh, speak or just breathe out we send a fine spray of liquid drops into the air. These droplets are so tiny that they remain floating in the air for a long time. They may be breathed in by other people or fall on to exposed food (Figure 12.2). If the droplets contain viruses or bacteria they may cause disease when they are eaten with food or inhaled.

Virus diseases like colds, flu, measles and chickenpox are spread in this way. So are the bacteria (*Streptococcus*) that cause sore throats. When the water in the droplets evaporates, the bacteria often die as they dry out. The viruses remain infectious, however, floating in the air for a long time.

In buses, trains, cinemas and night clubs the air is warm and moist, and full of floating droplets. These are places where you are likely to pick up one of these infections.



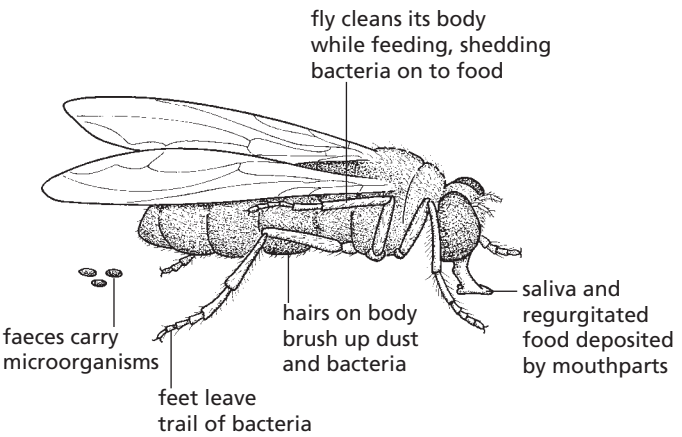
▲ **Figure 12.2** Droplet infection. The visible drops expelled by this sneeze will soon sink to the floor, but smaller droplets will remain suspended in the air

Contamination by houseflies

Flies walk about on food. They place their mouthparts on it and pump saliva onto the food. Then they suck up the digested food as a liquid.

This would not matter much if flies fed only on clean food, but they also visit decaying food or human faeces. Here they may pick up bacteria on their feet or their mouthparts. They then land on our food and the bacteria on their bodies are passed to the food. Figure 12.3 shows several ways in which this can happen.

Food poisoning, amoebic dysentery and polio can be spread by houseflies.



▲ **Figure 12.3** Transmission of bacteria by houseflies

Mechanical barriers

Although many bacteria live on the surface of the skin, the outer layer of the epidermis (see 'Homeostasis' in Chapter 14) usually acts as a barrier that stops them getting into the body. But, if the skin is cut or damaged, the bacteria may get into the deeper tissues and cause infection.

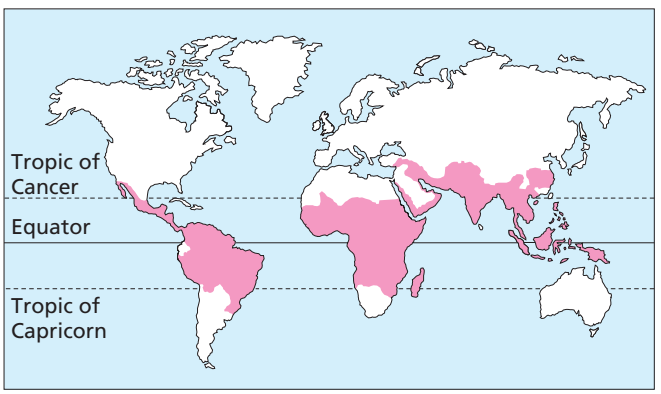
Hairs in the nose help to filter out bacteria that are breathed in. However, if air is breathed in through the mouth, this defence is bypassed.

Chemical barriers

The acid conditions in the stomach destroy most of the bacteria that may be taken in with food. Mucus produced by the lining of the trachea and bronchi traps many bacteria. The ciliated cells of these organs carry the trapped bacteria away from the lungs.

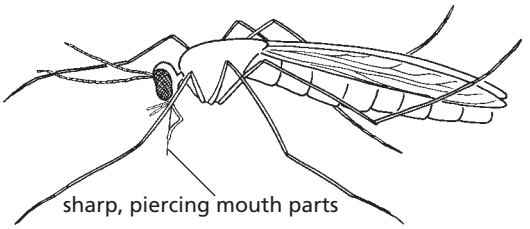
Mosquitoes and malaria

About 219 million people suffer from malaria in 87 countries (Figure 12.4). In 2017 there were an estimated 435 000 malaria deaths according to the World Health Organization.

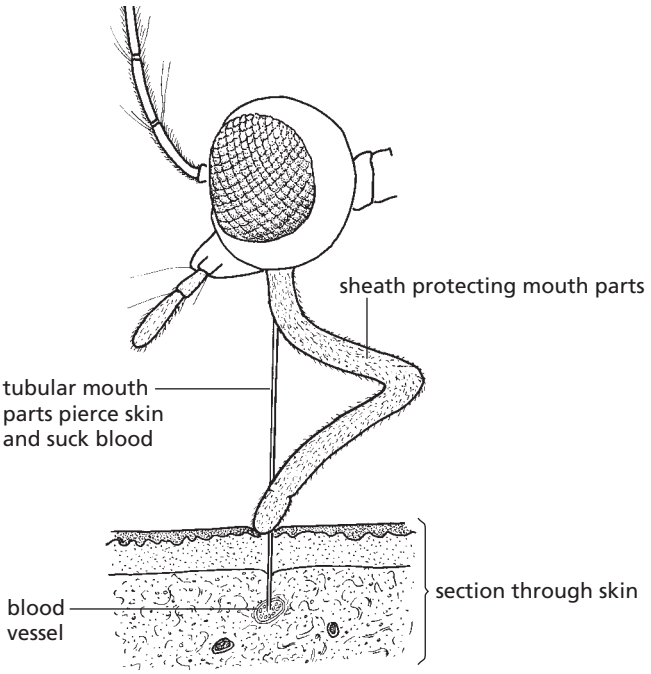


▲ **Figure 12.4** The worldwide distribution of malaria

The disease is caused by a protozoan parasite called *Plasmodium,* which is transmitted from person to person by the bites of infected mosquitoes of the genus *Anopheles*. The mosquito is said to be the **vector** of the disease. When a mosquito 'bites' a human, it inserts its sharp, pointed mouthparts through the skin until they reach a capillary (Figure 12.5). The mosquito then injects saliva, which stops the blood from clotting. If the mosquito is infected, it will also inject hundreds of malarial parasites.



(a) mosquito about to feed

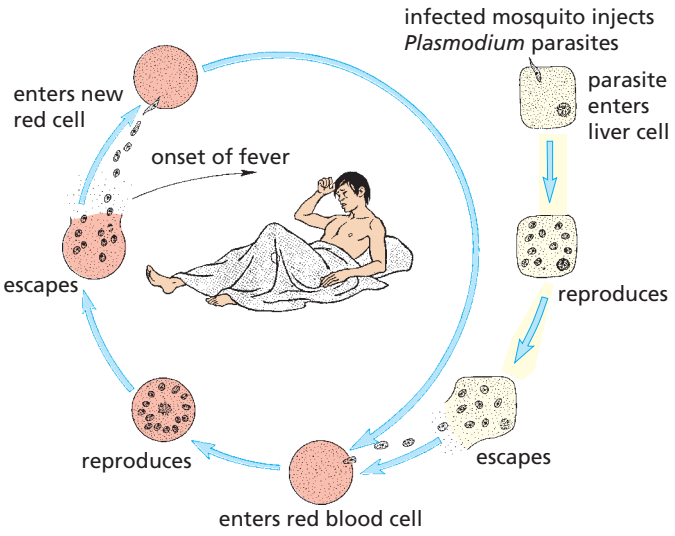


(b) mosquito head and mouth parts

▲ **Figure 12.5** Mosquito feeding on blood

The parasites reach the liver via the circulation and burrow into the liver cells where they reproduce. A week or two later, the daughter cells break out of the liver cells and invade the red blood cells. Here they reproduce rapidly and then escape from the original red cells to invade others (Figure 12.6).

The cycle of reproduction in the red blood cells takes 2 or 3 days (depending on the species of *Plasmodium*). Each time the daughter plasmodia are released simultaneously from thousands of red blood cells, the patient experiences the symptoms of malaria. These are chills accompanied by violent **shivering**, followed by a fever and profuse sweating. With so many red blood cells being destroyed, the patient will also become anaemic (see 'Diet' in Chapter 8).



▲ **Figure 12.6** *Plasmodium*, the malarial parasite

If a mosquito sucks blood from an infected person, it will take up the parasites in the red blood cells. The parasites reproduce in the mosquito and finally invade the salivary glands, ready to infect the next human.

Control

There are drugs that kill the parasites in the bloodstream but they do not reach those in the liver. The parasites in the liver may emerge at any time and start the cycle again. If these drugs are taken by a healthy person before entering a malarious country, they kill any parasites as soon as they are injected. This is a protective or **prophylactic** use of the drug.

Unfortunately there are now many mutant forms of *Plasmodium* that have developed resistance to these drugs.

A great deal of work has been devoted to finding an effective **vaccine**, without much success. Trials are currently taking place of a vaccine that may offer at least partial protection against the disease.

The most far-reaching form of malarial control is based on the elimination of the mosquito. It is known that mosquitoes lay their eggs in stagnant water and that the larvae hatch, feed and grow in the water, but have to come to the surface to breathe air.

Spraying stagnant water with oil and **insecticides** suffocates or poisons the larvae and pupae. Spraying must include not only lakes and ponds but any accumulation of fresh water that mosquitoes can reach, including drains, gutters, tanks, tin cans and old car tyres. By draining swamps and turning sluggish rivers into swifter streams, the breeding grounds of the mosquito are destroyed.

Spraying the walls of dwellings with chemicals like DDT was once very effective because the insecticide remained active for several months and the mosquito picked up a lethal dose merely by settling on the wall. See page 348 for further details about the use of DDT and its effects on the environment.

However, in at least 60 countries, many species of *Anopheles* have developed resistance to these insecticides and this method of control is now far less effective. The emphasis has changed back to the removal of the mosquito's breeding grounds or the destruction of the larvae and pupae.

Attempts have also been made to sterilise male mosquitoes by exposing them to radiation. When they are released into the population, the next generation fails.

Using new scientific approaches to the problem, mosquitoes are being genetically engineered to produce sterile males and also to produce transgenic females which have a flightless **phenotype**. When introduced to a population, numbers of mosquitoes should drop dramatically, reducing the risk of infection.

AIDS and HIV

The initials of AIDS stand for acquired immune deficiency syndrome. (A syndrome is a pattern of symptoms associated with a particular disease.) The virus that causes AIDS is the human immunodeficiency virus (HIV).

After a person has been infected, years may pass before symptoms develop. So, people may carry the virus but not show any symptoms. However, they can still infect other people. It is not known for certain what proportion of HIV carriers will eventually develop AIDS; it could be 30–50%, or more.

Transmission

HIV is transmitted by direct infection of the blood. Drug users who share needles contaminated with infected blood run a high risk of the disease. It can also be transmitted sexually, between both men and women if they are infected and have sex without using condoms or femidoms. HIV is therefore an STI.

Haemophiliacs have also fallen victim to AIDS. Haemophiliacs must inject themselves with a blood product that contains a clotting factor. Before the risks were recognised, infected carriers sometimes donated blood, which was used to produce the clotting factor.

Babies born to HIV carriers may become infected with HIV. This can happen through the placenta as the fetus develops, during birth or from the mother's milk. The rate of infection varies from about 40% in parts of Africa to 14% in Europe. If the mother is given drug therapy during labour and the baby is given drug therapy within 3 days of birth, this method of transmission is reduced.

There is no evidence to suggest that the disease can be passed on by droplets (see Figure 12.2 on page 187), by saliva or by normal everyday contact.

When AIDS first appeared there were no effective drugs. Today, there is a range of drugs that can be given separately or as a combination, which slow the progress of the disease. Research to find a vaccine and more effective drugs is ongoing, but treatment is much more effective now.

There is a range of blood tests designed to detect HIV infection. These tests do not detect the virus but do indicate whether antibodies to the virus are in the blood. If HIV antibodies are present, the person is said to be **HIV positive**. The tests vary in their reliability and some are too expensive for widespread use.

Control of the spread of HIV

The best way to avoid HIV infection is to avoid having sexual intercourse with an infected person. However, the symptoms of the disease are often not obvious and it is difficult to recognise an infected individual. So, the disease is avoided by not having sexual intercourse with a person who *might* have the disease. This is a good reason, among many others, for being faithful to one partner.

The risk of catching a sexually transmitted disease can be greatly reduced if the man uses a condom or if a woman uses a Femidom. These act as barriers to bacteria or viruses.

If a person suspects that he or she has caught HIV, it is important to get treatment straight away. Information about treatment can be obtained by searching online. Treatment is always confidential. The patients must, however, make sure that anyone they have had sexual contact with also gets treatment.

Controlling the spread of cholera and other diseases

Clean water supply

The intestines contain bacteria and some of these bacteria will pass out with the faeces. If the faeces get into streams or rivers, the bacteria may be carried into reservoirs of water used for drinking. Even if faeces are left on the soil or buried, rainwater may wash the bacteria into a nearby stream. If disease bacteria get into water supplies used for drinking, hundreds of people can become infected.

To prevent this method of infection, drinking water needs to be purified and faeces must be made harmless, a process involving **sewage treatment**.

Water treatment

On a small scale, simply boiling the water used for drinking will destroy any pathogens. On a large scale, water supplies are protected by (a) making sure that untreated human sewage cannot reach them and (b) treating the water to make it safe.

The treatment needed to make water safe for drinking depends on where the water comes from. Some sources (e.g. mountain streams) may be almost pure; others (e.g. slow-moving rivers) may be contaminated.

The object of the treatment is to remove all microorganisms that might cause disease. This is done by filtration and chlorination. Chlorine kills the pathogens.

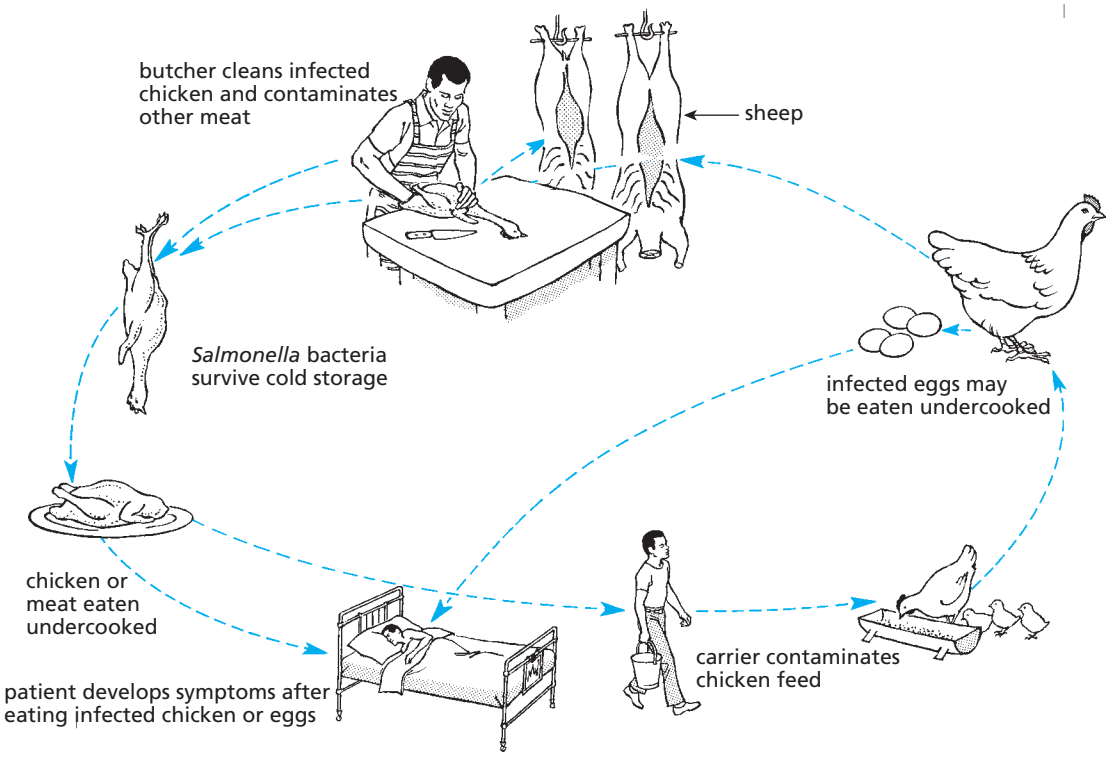
Hygienic food preparation

The presence of *Salmonella* bacteria in food is one of the commonest causes of food poisoning. The bacteria present are killed when meat is cooked or milk is pasteurised. Infection is most likely if untreated milk is drunk, meat is not properly cooked, or cooked meat is contaminated with bacteria transferred from raw meat (Figure 12.7). Frozen poultry must be thoroughly defrosted before cooking, otherwise the inside of the bird may not get hot enough during cooking to kill the *Salmonella*.

So, to avoid the disease, all milk should be pasteurised and meat should be thoroughly cooked. People like shop assistants and cooks should not handle cooked food at the same time as they handle raw meat. If they must do so, they should wash their hands thoroughly between the two activities.

The liquid that escapes when a frozen chicken is defrosted may contain *Salmonella* bacteria. The dishes and kitchen tools used while the bird is defrosting must not be allowed to come into contact with any other food.

Uncooked meat or poultry should not be kept next to any food that is likely to be eaten without cooking. Previously cooked meat should never be warmed up; the raised temperature speeds up the reproduction of any bacteria present. The meat should be eaten cold or cooked at a high temperature.



▲ **Figure 12.7** Transmission of *Salmonella* food poisoning

Good personal hygiene

Salmonella bacteria, and bacteria that cause typhoid, are present in the faeces of infected people. These may reach food from the unwashed hands of the sufferer.

People recovering from one of these diseases may feel quite well, but bacteria may still be present in their faeces. If they do not wash their hands thoroughly after going to the lavatory, they may have small numbers of bacteria on their fingers. If they then handle food, the bacteria may be passed to the food. When this food is eaten by healthy people, the bacteria will multiply in their bodies and give them the disease.

People working in food shops, kitchens and food-processing factories could infect thousands of other people in this way if they were careless about their personal cleanliness.

In summary, people who handle and prepare food need to be extremely careful about their personal hygiene. It is vital that they wash their hands before touching food, especially after they have visited the lavatory (Figure 12.8). Hand-washing is also important after handling raw meat, especially poultry (see Figure 12.7). Food on display in shops needs to be protected (Figure 12.9).

▲ **Figure 12.8** Hygienic handling of food. Shop assistants avoid handling meat and shellfish with their fingers by using disposable gloves

Some people carry intestinal pathogens without showing any symptoms of disease. These people are called carriers. Once identified, they should not be allowed to work in canteens or food-processing factories.

▲ **Figure 12.9** Protection of food on display. The glass barrier stops customers from touching the products, keeps flies off the food and helps stop droplets from coughs and sneezes falling on the food

Waste disposal

Waste from domestic or commercial premises should be stored in dustbins or garbage cans made of galvanised steel or strong plastic, with a closely fitted lid to keep out flies and scavenging animals. If this is not done, pathogens will breed in the waste and become a source of disease organisms. The waste is taken away and disposed of by burning or burying deep enough to prevent rats using it as food, or (less effectively) tightly packed to keep out flies and vermin.

Sewage treatment

Sewage contains bacteria, including cholera bacteria, from the human intestine that can be harmful. These bacteria must be destroyed to prevent the spread of intestinal diseases, especially cholera. Rainwater from the streets is also combined with the sewage.

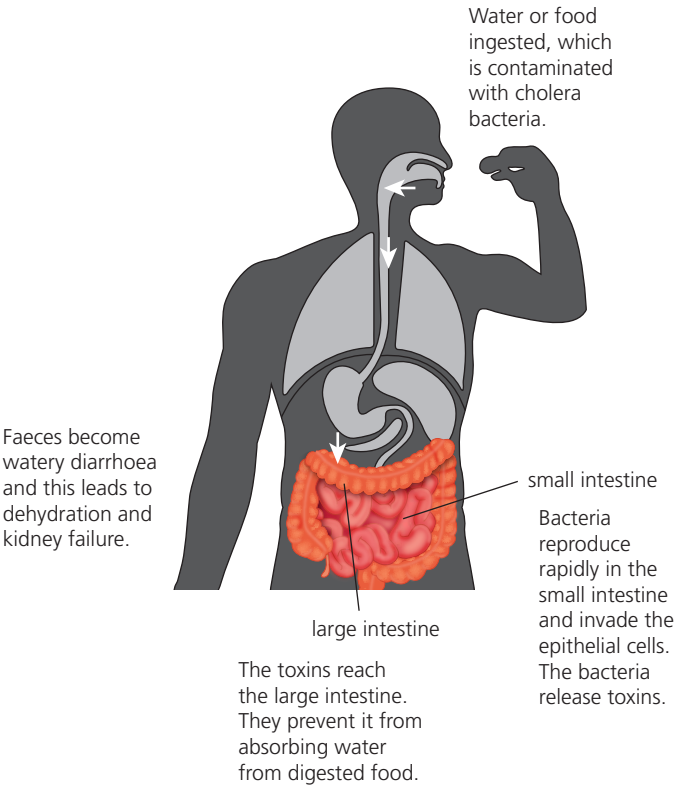
Inland towns must make their sewage harmless in a sewage treatment plant before discharging the effluent into rivers. A sewage works removes solid and liquid waste from the sewage so that the water leaving the works is safe to drink. The process of chlorination kills any bacteria present in the water.

Cholera

This disease is caused by the bacterium *Vibrio cholera,* which causes serious diarrhoea. Treatment involves rehydration and replacement of the salts lost (given by injecting a carefully controlled solution into the bloodstream). It also involves the use of an **antibiotic** such as tetracycline to kill the bacteria. The bacteria grow well in dirty water, often water which is contaminated by sewage. They are transmitted when the water is drunk or used to wash food. Long-term methods of control are to dispose of human sewage safely, making sure that drinking water is free from bacteria and stopping food from being contaminated.

How cholera causes diarrhoea

When the *Vibrio cholera* bacteria are ingested, they reproduce in the small intestine and invade its epithelial cells (Figure 12.10). As the bacteria become embedded they release toxins (poisons), which irritate the intestinal lining. This results in the secretion of large amounts of water and salts, including chloride ions. The salts decrease the osmotic potential of the gut contents, attracting more water from surrounding tissues and blood by osmosis (see 'Osmosis' in Chapter 3). This makes the undigested food much more watery, leading to serious diarrhoea. The loss of body fluids and salt leads to dehydration and kidney failure.



▲ **Figure 12.10** How cholera causes diarrhoea

Going further

Salmonella food poisoning

One of the commonest causes of food poisoning is the toxin produced by the bacteria *Salmonella typhimurium* and *S. enteritidis*. These bacteria live in the intestines of cattle, chickens and ducks without causing disease symptoms. However, humans may develop food poisoning if they drink milk or eat meat or eggs that are contaminated with *Salmonella* bacteria from the alimentary canal of an infected animal.

Intensive methods of animal farming may add to a spread of infection unless care is taken to reduce the exposure of animals to infected faeces.

The symptoms of food poisoning are diarrhoea, vomiting and abdominal pain. They happen from 12 to 24 hours after eating the contaminated food. Although these symptoms are unpleasant, the disease is not usually serious and does not need treatment with drugs. However, elderly people and very young children may be made very ill by food poisoning.

Recently there has been an increase in outbreaks of *Salmonella* food poisoning in which the bacteria are resistant to antibiotics. Some scientists suspect that this results from the practice of feeding antibiotics to farm animals to increase their growth rate. This could allow populations of drug-resistant salmonellae to develop.

Some types of food poisoning result from poisons (toxins) that are produced by bacteria that get into food. Cooking kills the bacteria in the food but does not destroy the toxins that cause the illness. Only one type of this kind of food poisoning, called botulism, is dangerous. It is also very rare.

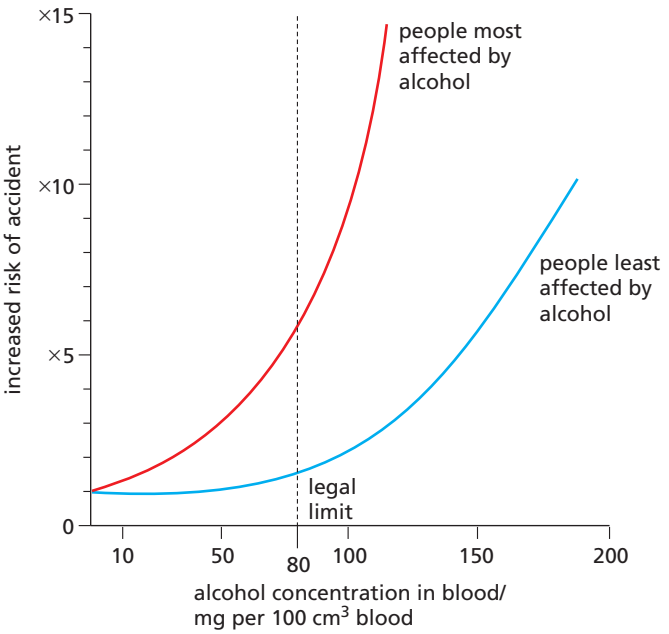
In the 1970s another genus of bacteria, *Campylobacter*, was identified as a cause of food poisoning. This bacterium causes acute abdominal pains and diarrhoea for about 24 hours. The sources of infection are thought to be undercooked meat, particularly burgers.

Effects of alcohol consumption and smoking

Alcohol

The alcohol in wine, beer and spirits is a depressant of the **central nervous system**. Small amounts give a sense of wellbeing, with a release from anxiety, however alcohol eventually makes people feel more depressed. Alcohol consumption is accompanied by a drop in performance in any activity requiring skill. It also gives a misleading sense of confidence in spite of the fact that the person's judgement is clouded. A drunk driver usually thinks he or she is driving extremely well.

Even a small amount of alcohol in the blood increases our reaction time (the interval between receiving a **stimulus** and making a response). In some people, the reaction time is doubled even when the alcohol in the blood is well below the legal limit laid down for car drivers (Figure 12.11). This can make a big difference to the time needed for a driver to apply the brakes after seeing a hazard such as a child running into the road.



▲ **Figure 12.11** Increased risk of accidents after drinking alcohol. People vary in their reactions to alcohol. Body weight, for example, makes a difference

Alcohol causes **vasodilation** in the skin, giving a sensation of warmth but in fact leading to a greater loss of body heat (see 'Homeostasis' in Chapter 14).

Alcohol acts as a depressant. A concentration of 500 mg of alcohol in 100 cm^3 of blood results in unconsciousness. More than this will cause death because it stops the breathing centre in the brain. The liver treats alcohol as a toxin: 90% of alcohol taken in is **detoxified** in the liver (along with other toxins). The process of detoxification involves the oxidation of alcohol to carbon dioxide and water. Only 10% is excreted by the kidneys. On average, the liver can oxidise about 75 mg alcohol per 1 kg body weight per hour. This rate varies considerably from one individual to another, but it indicates that it would take about 3 hours to oxidise the alcohol in a pint of beer or a glass of wine. If the alcohol intake exceeds this rate of oxidation, the level of alcohol in the blood builds up to toxic proportions; that is, it leads to **intoxication**.

Some people build up a tolerance to alcohol and this may lead to both emotional and physical dependence (alcoholism). High doses of alcohol can cause the liver cells to form too many fat droplets, leading to the disease called **cirrhosis**. A diseased liver is less able to stop poisonous substances in the intestinal blood from reaching the general circulation.

Alcohol reduces inhibitions because it depresses that part of the brain which causes self-control. This can lead to reduced self-control and irresponsible behaviour such as vandalism and aggression.

Smoking

The short-term effects of smoking cause the bronchioles to constrict and the cilia lining the air passages to stop beating. The smoke also makes the lining produce more mucus. **Nicotine**, the addictive component of tobacco smoke, casues an increase in the rate of the heartbeat and a rise in blood pressure. It may, in some cases, cause an erratic and irregular heartbeat. **Tar** in cigarette smoke is thought to be the main cause of lung cancer in smokers. **Carbon monoxide** binds permanently with haemoglobin in red blood cells, reducing a smoker's ability to provide oxygen to respiring cells. This results in a smoker getting out of breath more easily and it reduces physical fitness.

The long-term effects of smoking may take many years to develop but they are severe, disabling and often lethal.

Lung cancer

Cancer is a term used for diseases in which cells become abnormal and divide out of control. They can then move around the body and invade other tissues. A chemical that causes cancer is known as a **carcinogen**. Carcinogens present in cigarette smoke, such as tar, increase the risk of lung cells becoming cancerous. Tumours develop. These are balls of abnormal cells which do not allow gaseous exchange like normal lung cells.

Many studies have now demonstrated how cigarette smoke damages lung cells, confirming that smoking does cause cancer. The higher the number of cigarettes smoked, the greater the risk of lung cancer.

Chronic obstructive pulmonary disease (COPD)

This term covers a number of lung diseases, which include chronic bronchitis, emphysema and chronic obstructive airways disease. A person suffering from COPD will experience difficulties with breathing, mainly because of narrowing of the airways (bronchi and bronchioles). Symptoms of COPD include breathlessness when active, frequent chest infections and a persistent cough with phlegm (sticky mucus).

Emphysema

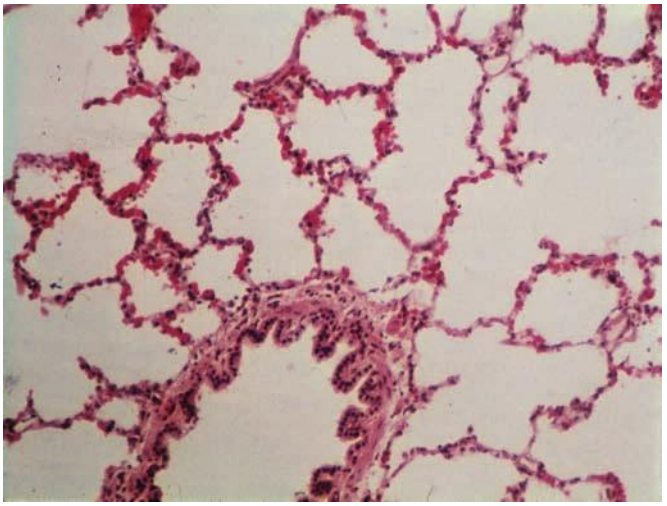
Emphysema is a breakdown of the alveoli. The action of one or more of the substances in tobacco smoke weakens the walls of the alveoli. The irritant substances in the smoke cause a 'smokers' cough' and the coughing bursts some of the weakened alveoli. In time, the absorbing surface of the lungs is greatly reduced (Figure 12.12). Then the smoker cannot oxygenate his or her blood properly and the least exertion makes the person breathless and exhausted.

Chronic bronchitis

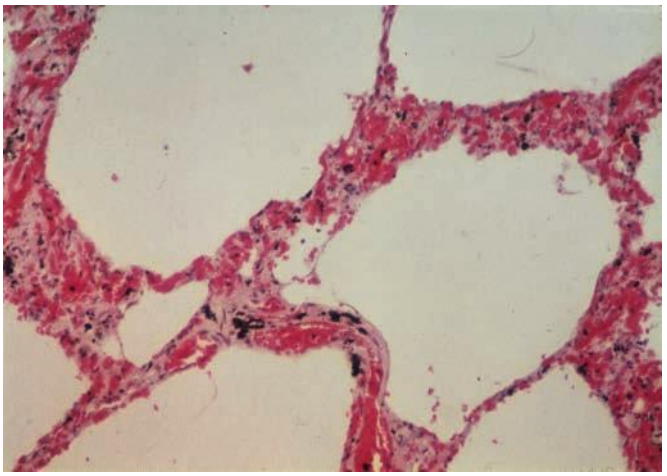
The smoke stops the cilia in the air passages from beating, so the irritant substances in the smoke and the excess mucus collect in the bronchi. This leads to inflammation known as **bronchitis**. Over 95% of people suffering from bronchitis are smokers and they have a 20 times greater chance of dying from bronchitis than non-smokers.

Heart disease

Coronary heart disease is the leading cause of death in most developed countries. It results from a blockage of coronary arteries by fatty deposits. This reduces the supply of oxygenated blood to the heart muscle and, sooner or later, leads to heart failure (see Chapter 11). High blood pressure, diets with too much animal fat and lack of exercise are also thought to be causes of heart attack, but about a quarter of all deaths due to coronary heart disease are thought to be caused by smoking.



(a) Normal lung tissue showing a bronchiole and about 20 alveoli (× 200)



(b) Lung tissue from a person with emphysema. This is the same magnification as **(a)**. The alveoli have broken down leaving only about five air sacs, which provide a much reduced absorbing surface.

▲ **Figure 12.12** Emphysema

The nicotine and carbon monoxide from cigarette smoke increase the tendency for the blood to clot and so block the coronary arteries, already partly blocked by fatty deposits. The carbon monoxide increases the rate at which the fatty material is deposited in the arteries (see Figure 11.10 on page 172).

Other risks

About 95% of patients with disease of the leg arteries are cigarette smokers; this condition is the most frequent cause of leg amputations.

Strokes due to arterial disease in the brain are more frequent in smokers.

Cancer of the bladder, ulcers in the stomach and duodenum, tooth decay, gum disease and tuberculosis all occur more often in smokers.

Babies born to women who smoke during pregnancy are smaller than average, probably as a result of reduced oxygen supply caused by the carbon monoxide in the blood. In smokers, there is twice the frequency of miscarriages, a 50% higher still-birth rate and a 26% higher death rate of babies.

A recent estimate is that one in every three smokers will die as a result of their smoking habits. Those who do not die at an early age will probably be seriously disabled by one of the conditions described above.

Passive smoking

It is not only the smokers themselves who are harmed by tobacco smoke. Non-smokers in the same room are also affected. One study has shown that children whose parents both smoke breathe in as much nicotine as if they were themselves smoking 80 cigarettes a year.

Statistical studies also suggest that the non-smoking wives of smokers have an increased chance of lung cancer.

Test yourself

1 After a disaster like an earthquake the survivors are urged to boil all drinking water. Suggest why this advice is given.
2 Explain why coughing or sneezing without covering the mouth and nose with a handkerchief is thought to be careless behaviour.
3 Describe how the body defends itself against a harmful bacterium that has arrived
   a on the hand
   b in a bronchus
   c in the stomach.
4 a What are the two main lines of attack on malaria?
   b What is the connection between stagnant water and malaria?
   c What is the principal 'set-back' in the battle against malaria?
5 State three ways in which a baby can become infected with HIV.
6 State two ways in which the spread of STIs can be controlled.
7 Explain why HIV cannot be treated with antibiotics.
8 List at least four effects of the excessive consumption of alcohol.
9 What are
   a the immediate effects and
   b the long-term effects of tobacco smoke on the trachea, bronchi and lungs?
10 Apart from lung cancer, what other diseases are probably caused by smoking?

Antibiotics

FOCUS POINTS

- ★ How are antibiotics used to treat bacterial infections?
- ★ What reduces the effectiveness of antibiotics?
- ★ Why does using antibiotics only when essential limit the development of resistant bacteria such as MRSA?
- ★ What do antibiotics kill?

A drug is any substance taken into the body that modifies or affects chemical reactions in the body. A drug may be taken legally to reduce a symptom like a headache or to treat a **bacterial infection** (medicinal drugs). Drugs can also be illegal. These are taken to provide stimulation, help sleep or create hallucinations (recreational drugs). Drugs are present in many products, such as tea, coffee and *energy drinks* (caffeine); tobacco (nicotine); and alcoholic drinks (alcohol).

Any substance used in medicine to help our bodies fight illness or disease is called a drug.

The ideal drug for curing disease would be a chemical that destroyed the pathogen without harming the tissues of the host. In practice, modern antibiotics like **penicillin** come near to this ideal for bacterial infections.

A tiny minority of bacteria are harmful (pathogenic). Figure 12.1 shows some examples and the diseases they cause.

Antibiotics attack bacteria in a variety of ways. Some of them disrupt the production of the cell wall to prevent the bacteria from reproducing, or even cause them to burst open; some interfere with protein synthesis. This stops the growth of the bacteria.

Animal cells do not have cell walls, and the cell structures involved in protein production are different. As a result, antibiotics do not damage human cells, although they may produce some side-effects like allergic reactions.

Not all bacteria are killed by antibiotics. Some bacteria have the ability to mutate into forms that are resistant to these drugs.

For this reason, it is important not to use antibiotics in a diluted form, for too short a period or for minor complaints. These practices lead to a build-up of a resistant population of bacteria. Antibiotic resistance reduces the effectiveness of antibiotics. Also, antibiotic drug resistance can be passed from harmless bacteria to pathogens.

Antibiotics and viral diseases

Antibiotics are not effective in the treatment of diseases caused by viruses. When a patient visits a doctor with, for example, a throat infection, the doctor will look at the symptoms of the infection and decide whether they are caused by a virus or by a bacterium. It is pointless to prescribe antibiotics if the symptoms are caused by a virus. Doing so would also risk reducing the effectiveness of the antibiotic.

The reason antibiotics are not effective against viral diseases is because antibiotics work by disrupting structures in bacteria like cell walls and membranes. They can also disturb processes to do with protein synthesis and the replication of DNA. Viruses have totally different characteristics to bacteria, so antibiotics do not affect them.

Development of resistant bacteria

To reduce the risk of resistant strains of bacteria such as **MRSA** developing, doctors now have to be much more cautious about prescribing antibiotics.

Patients need to be aware of the importance of completing a course of antibiotics. Again, this reduces the risk of resistant strains developing. See Chapter 17 for more details.

Going further

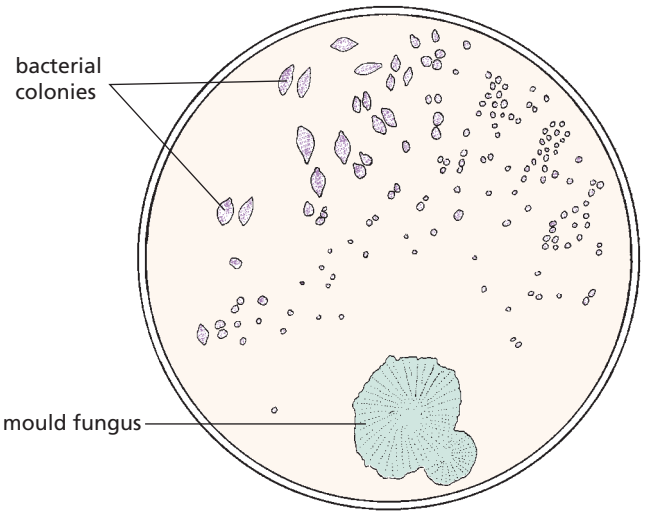
Ideas about antibiotics

Alexander Fleming (1881–1955)

Before 1934 there were few effective drugs. Some plant-based preparations may have been useful; many of our present-day drugs are obtained from or based on plant products. Quinine, for example, was used for the treatment of malaria and was extracted from a specific kind of tree bark. The active ingredient in aspirin (salicylic acid) was originally found in the bark of willow trees.

In 1935, a group of chemicals called sulfanilamides were found to be effective against some bacterial diseases like blood poisoning, pneumonia and septic wounds.

Fleming had discovered penicillin in 1928, 7 years before the use of sulfanilamides, but he had been unable to purify it and test it on humans. Fleming was a bacteriologist working in a London hospital. He was studying different strains of *Staphylococcus* bacteria. He had made some cultures on agar plates and left them on the laboratory bench during a 4-week holiday. When he returned, he noticed that one of the plates had been contaminated by a mould fungus and that around the edges of the mould there was a clear zone with no bacteria growing (Figure 12.13).



▲ **Figure 12.13** Appearance of the *Staphylococcus* colonies on Fleming's Petri dish

Fleming concluded that a substance had diffused out of the mould colony and killed the bacteria. The mould was identified as *Penicillium notatum* and he called the anti-bacterial chemical penicillin. Fleming went on to grow the *Penicillium* on a liquid meat broth medium. He showed that the broth contained penicillin, which stopped the growth of a wide range of bacteria.

Two research assistants at the hospital then tried to obtain a pure sample of penicillin, free from all the other substances in the broth. Although they succeeded, the method was awkward and the product was unstable. By this time, Fleming decided that penicillin would be too difficult to extract and too unstable to be of medical value.

In 1939, Howard Florey (a pathologist) and Ernst Chain (a biochemist), working at Oxford University, succeeded in preparing reasonably pure penicillin and making it stable. This was achieved by freeze-drying. The method allowed a stable, water-soluble powder form of penicillin to be produced.

World War II created a demand to produce large quantities of penicillin. Doing this certainly saved many lives that would otherwise have been lost as a result of infected wounds.

After Ernst Chain had worked out the molecular structure of penicillin, it became possible to modify it chemically. Then, scientists were able to produce other forms of penicillin that attacked a different range of bacteria or had different properties. For example, ampicillin is a modified penicillin that can be swallowed rather than given by injection.

Because penicillin was the product of a mould, chemists searched for other moulds, particularly those present in the soil, which might produce antibiotics. Several of these were discovered, including streptomycin (for tuberculosis), chloramphenicol (for typhoid), and aureomycin and terramycin (broad spectrum antibiotics, which attack a wide range of bacteria).
The ideal drug is one that kills or stops the growth of harmful cells, like bacteria or cancer cells, without damaging the body cells. Scientists have been trying for years to find a perfect drug that works exclusively on its target cells. For bacterial diseases, antibiotics nearly achieve perfection. However, the bacteria do seem able to develop resistant forms after a few years.

Test yourself

11 Study the images of a virus in Figure 2.36 on page 38 and a bacterium in Figure 1.9, page 6.
   a Make a table to compare their structures.
   b Convert the scales on the diagrams into standard form.
12 The length of the bacterial cell in Figure 1.9 is 55 mm. If its actual length is 2.0 μm, calculate the magnification of the image.
13 Figure 17.29 on page 306 shows how **mutation** in bacteria can lead to drug resistance. Starting with one single bacterium, if the bacterium reproduces every 20 minutes and mutants appear as shown in the diagram, how long will it take to produce over one million drug-resistant mutants?

Defences against diseases

FOCUS POINTS

- ★ What is active immunity?
- ★ What is an antigen?
- ★ What is an antibody?
- ★ How do antibodies defend against disease?
- ★ How is active immunity gained after an infection by a pathogen or by vaccination?
- ★ What is the process of vaccination?
- ★ How does vaccination control the spread of diseases?
- ★ What is passive immunity?
- ★ Why is breast-feeding important for developing passive immunity in infants?
- ★ When are memory cells produced?
- ★ What are the body's main lines of defence against disease?
- ★ How does HIV affect the immune system?

When bacteria get through the mechanical and chemical barriers, the body has two more ways of defending itself – white blood cells and antibodies, produced by white blood cells. One type of white blood cell fights infection by engulfing bacteria (a process called phagocytosis) and digesting them. Further details of this process is described in the section 'Blood' in Chapter 11. Another type produces antibodies that attach themselves to bacteria, making it easier for other white blood cells to engulf them.

Antibodies and immunity

Key definitions

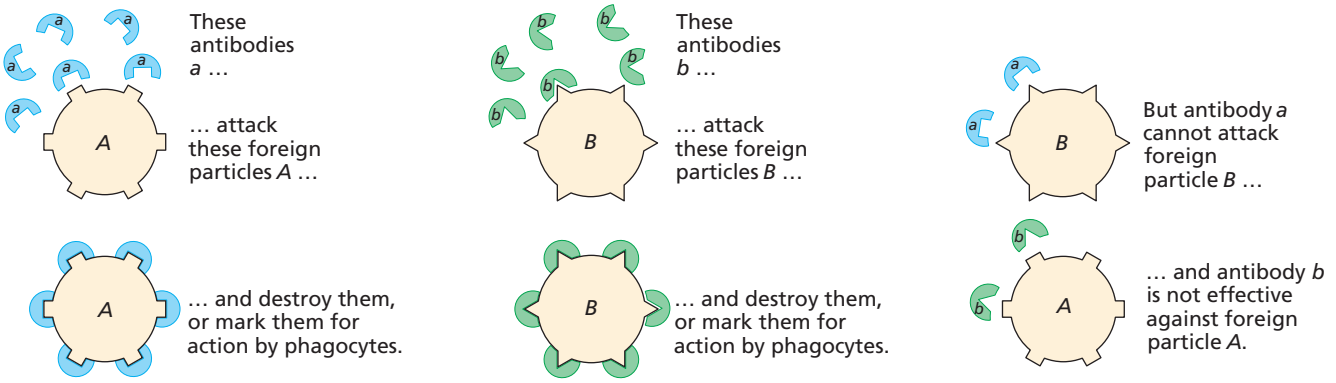
Active immunity is the defence against a pathogen by antibody production in the body.

Antibodies are proteins that bind to antigens, leading to direct destruction of pathogens or marking of pathogens for destruction by phagocytes.

On the surface of all cells there are chemical substances called **antigens**, which have **specific** shapes. Specific antibodies also have **complementary shapes** that fit specific antigens. Lymphocytes are a type of white blood cell. They produce proteins called antibodies that directly attack the antigens of bacteria or any alien cells or proteins that invade the body. They also attach to the antibodies, marking the surface of the bacteria and making it easier for the phagocytes to find and ingest them. Then they clump the bacteria together or neutralise the toxins (poisonous proteins) that the bacteria produce.

Each antibody is very specific. This means that an antibody that attacks a typhoid bacterium will not affect a pneumonia bacterium. This is shown in the form of a diagram in Figure 12.14.

Some of the lymphocytes that produced the specific antibodies stay in the lymph nodes as **memory cells** for some time. They divide rapidly and make more antibodies if the same antigen gets into the body again. This means that the body has become immune to the disease caused by the antigen. This explains why, once you have recovered from measles or chickenpox, for example, you are very unlikely to catch the same disease again. This is called active immunity. Active immunity can also be gained by **vaccination**. You may also inherit some forms of **immunity** or gain antibodies from your mother's milk (see 'Sexual reproduction in humans' in Chapter 16).



▲ **Figure 12.14** Antibodies are specific

Going further

B and T lymphocytes

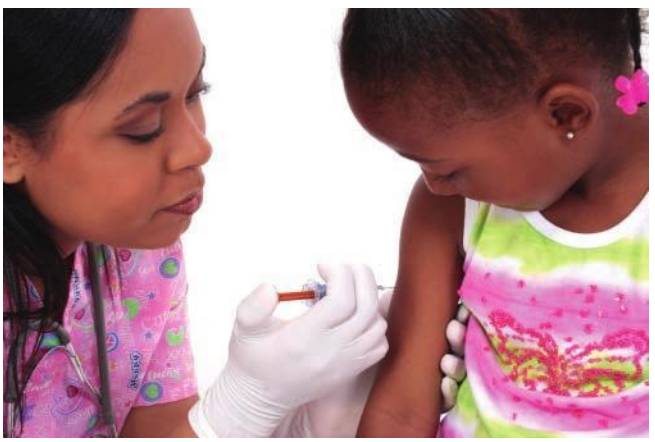
There are two main types of lymphocyte. Both types undergo rapid cell division in response to the presence of specific antigens. Their functions are different but they work together. The **B cells** (from **B**one marrow) become short-lived **plasma** cells and produce antibodies that are released into the blood. These antibodies may attack antigens directly or stick to the surface membrane of infected or unfamiliar cells, for example, cells carrying a virus, bacteria, cancer cells or transplanted cells.

'Killer' **T cells** (from the **T**hymus gland) have receptor molecules on their surface, which attach them to these surface antibodies. The T cells then kill the cell by damaging its cell membrane.

'Helper' T cells stimulate the B cells to divide and produce antibodies. They also stimulate the phagocytes to ingest any cells carrying antibodies on their surface.

Vaccination

The body's defences can be improved by vaccination. This involves a harmless form of the pathogen (bacteria or virus) being introduced into the body by injection (Figure 12.15) or swallowing. The presence of the foreign material triggers white blood cells to make specific antibodies to fight possible infection and produce memory cells. If the person is exposed to the disease later, defences are already in place to stop it developing (the person is **immune** to that disease). Without vaccination, white blood cells need to be exposed to the disease organism before they make the appropriate antibody. If the disease is potentially lethal, the patient could die before the white blood cells have time to act.



▲ **Figure 12.15** Vaccination. The girl is being vaccinated against rubella (German measles)

The material that is injected or swallowed is called a vaccine and is one of the following:

- Antigens from the pathogen.
- A harmless form of the microorganism, for example, the BCG inoculation against tuberculosis and the Sabin oral vaccine against polio (oral, in this context, means 'taken by mouth').
- The killed microorganisms, for example, the Salk anti-polio vaccine and the whooping cough vaccine.
- A toxoid, i.e. the inactivated toxin from the bacteria, for example, the diphtheria and tetanus vaccines. (A toxin is the poisonous substance produced by certain bacteria, which causes the symptoms of the disease.)

Preventing spread of transmissible disease through vaccination

Routine vaccination not only protects the individual but also prevents the spread of transmissible disease. Diseases like diphtheria and whooping cough were once common and are now quite rare. This is the result of improved social conditions and routine vaccination. **Smallpox** was completely wiped out throughout the world by a World Health Organization programme of vaccination between 1959 and 1980.

A large proportion of a population needs to be immunised (ideally over 90%) to prevent an epidemic of a disease. When mass vaccination fails, the population is at risk of infection with potential epidemics resulting. An example of this was with the MMR vaccine in Britain. MMR is a combination of vaccines protecting against measles, mumps and rubella (German measles). A researcher and surgeon carried out a study, the results of which were interpreted as suggesting a link between the MMR vaccine and the frequency of autism and bowel disease in children. The percentage of people protected against measles, mumps and rubella dropped below 90% in some areas.

When the coronavirus (COVID-19) outbreak happened in December 2019, it was a virus that was new to science, so there was no vaccine available to give to populations. As a result, the infection spread rapidly around the world and became a pandemic.

There is a small risk of serious side-effects from vaccines, just as there is with all medicines. These risks are always far lower than the risk of catching the disease itself. For example, the measles vaccine carries a risk of 1 in 87 000 of causing encephalitis (swelling of the brain). This is much less than the risk of getting encephalitis as a result of catching measles. Also, the vaccines themselves are becoming much safer, and the risk of side-effects is now almost nil.

Going further

Global travel

In the 18th and 19th centuries, explorers, traders and missionaries carried European diseases to countries where the population had no natural immunity. It is thought that damaging epidemics of smallpox and measles in, for example, North American Indians and Australian aborigines, resulted from contact with infected Europeans.

Today, world travel is so common that it raises the possibility of travellers catching a disease in one country and carrying it into another place where the disease is rare or non-existent. Coronavirus was carried by business travellers and people visiting other countries for holidays or to see relatives.

An endemic disease is one that is constantly present in a population. If you plan to visit a country where an infectious disease is endemic, you are likely to be offered advice on vaccination. There is no vaccine against malaria but, if you are travelling to a country that has the disease, you will probably be advised to take a drug (e.g. chloroquine) that kills malarial parasites. This medication starts a week or more

before you travel. You continue to take it throughout your stay and for a few weeks after your return. Drugs like this, which help to stop you getting a disease, are called prophylactics.

Also, you may find your aircraft cabin being sprayed with insecticide to kill any malaria-carrying mosquitoes that might have entered.

If you visit a country where a disease (e.g. yellow fever) is endemic, you may need to produce a certificate of vaccination (Figure 12.16) before being allowed into a country where the disease is not present.

▲ **Figure 12.16** International certificate of vaccination

Passive immunity

Some diseases can be prevented or cured by injecting the patient with serum from a person who has recovered from the disease. Serum is plasma with the fibrinogen removed. A serum is prepared from the plasma given by blood donors.

People who have recently received an anti-tetanus inoculation will have made anti-tetanus antibodies in their blood. Some of these people volunteer to donate their blood, but their plasma is separated promptly and the red blood cells put back in their circulation. The anti-tetanus antibodies are then removed from the plasma. These are used to treat patients who are at risk of becoming infected by tetanus, for example, as a result of an accident. Antibodies against chickenpox and rabies can be produced in a similar way.

The temporary immunity gained by these methods is called **passive immunity** because the antibodies have not been produced by the patient. It is only temporary because it does not result in the formation of memory cells.

Antibodies pass across the placenta from the mother's blood to the developing fetus. Also, when a mother breastfeeds her baby, the milk contains some of the mother's white blood cells, which produce antibodies. When a baby is very young, its immune responses are not fully developed, so these antibodies give the baby protection against infection at a time when it is at risk. However, this is another case of passive immunity as it is only short-term protection: memory cells are not produced.

The effects of HIV on the immune system

HIV attacks certain kinds of lymphocyte (see 'Blood' in Chapter 11), so the number of these cells in the body decreases. Lymphocytes produce antibodies against infections. If the body cannot respond to infections through the immune system, it becomes vulnerable to pathogens that might not otherwise be life-threatening. As a result, the patient has little or no resistance to a wide range of diseases such as influenza, pneumonia, blood disorders, skin cancer or damage to the nervous system.

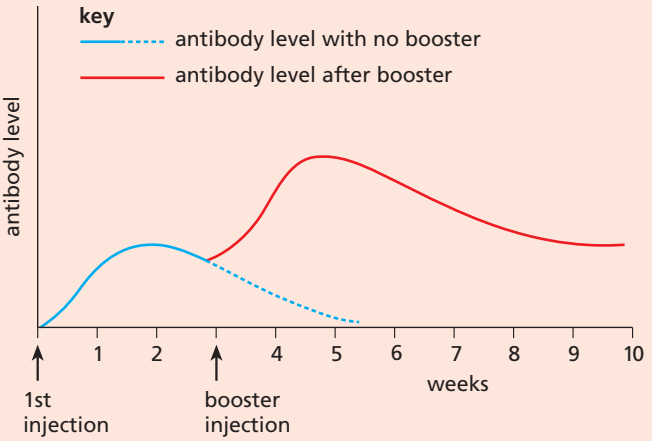
Test yourself

14 Describe how white blood cells protect us from bacterial infections.

15 Explain why vaccination against diphtheria does not protect you against polio as well.

16 Even if there have been no cases of diphtheria in a country for many years, children may still be vaccinated against it. Suggest why this is done.

17 Figure 12.17 shows the changes in the levels of antibody in response to an inoculation of a vaccine, followed by a booster injection 3 weeks later. Use your knowledge of the immune reaction to explain these changes.



▲ **Figure 12.17** Changes in the levels of antibody in response to inoculation of a vaccine

Going further

Ideas about disease transmission and microorganisms

Edward Jenner (1749–1823)

The history of immunisation is based on the disease smallpox, which is caused by a virus. Until recently it was a serious, worldwide disease causing hundreds of thousands of deaths.

It was known that people who had recovered from smallpox never caught the disease again. In the late 1600s this knowledge was used in countries like Greece, Turkey, China and India. Fluid from the blisters, which were a feature of the disease, was put into healthy people through cuts in the skin. The patient suffered a mild form of smallpox but became immune to the disease. However, it was a risky practice and some people developed smallpox and died as a result of this early type of vaccination.

In the 1750s, a surgeon called Robert Sutton improved the technique with great success. Edward Jenner is usually named as the person who introduced smallpox vaccination. He noticed that milkmaids sometimes caught an infection called cowpox from infected cows. When they were given a smallpox vaccination, they did not develop the mild symptoms of illness.

In 1796, Jenner conducted a vital, but risky, experiment. He took fluid from a cowpox blister on a milkmaid's hand and injected it into a young boy. Two months later, he inoculated the boy with smallpox and showed that the boy was immune. He published the result and the treatment started to be used throughout Europe, reducing deaths from smallpox by about two-thirds.

Jenner called his technique 'vaccination' to distinguish it from inoculation with smallpox. 'Vacca' is Latin for 'cow' and 'vaccinia' is the medical name for cowpox. We now know that viruses and bacteria often lose a lot of their harmfulness if they are allowed to pass through different animals or are cultured in a special way. These harmless microbes are called **attenuated**. Jenner did not know about viruses or attenuation but his clever observations, sensible conclusions and bold experiments resulted in far fewer people suffering.

In 1967, the World Health Organization started a programme to get rid of smallpox from the whole world. The plan was to trace all cases of smallpox and isolate the patients so that they could not pass on the disease. Everyone at risk was then vaccinated. By 1987 the disease had been wiped out.

Louis Pasteur (1822–1895)

Pasteur made great contributions to chemistry, biology and medicine. In 1854, as professor of chemistry at the University of Lille, he was asked by the French wine industry to investigate the problem of wines going sour.

He used a microscope to study the yeast cells that were present and suggested that these were the cause of the fermentation. He concluded that fermentation was the result of a living process in yeast and not caused only by a chemical change in the grape juice. Pasteur observed that the yeast cells were gradually replaced by microbes (which we now call bacteria). These seemed to change the alcohol into acetic and lactic acids.

Pasteur showed that souring was prevented by heating the wine to 120 °F (49 °C). He suggested that this was because the microbes responsible for souring had been killed by the heat and, if the wine was bottled straight away, they could not return. This process is now called pasteurisation.

Spontaneous generation

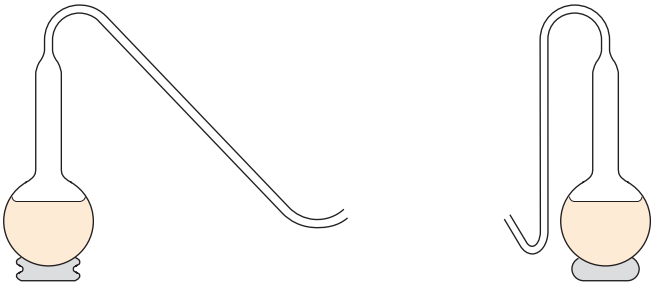
The microorganisms in decaying products could be seen under the microscope, but where did they come from? Many scientists claimed that they were the *result* of decay rather than the *cause*; they had arisen spontaneously in the decaying fluids.

In the 17th century, it was believed that organisms could be generated from decaying matter. The organisms were usually vermin like insects, worms and mice. An experiment was carried out in 1668 to challenge this idea. Meat left exposed to the air was compared with meat protected from blowflies by a gauze lid on the container. Maggots only appeared in the meat that the blowflies could get to.

This, and other experiments, disproved theories about the spontaneous generation of visible organisms, but the debate about the origin of microbes continued into the 1870s.

It was already known that if liquids were boiled for a period of time and then placed in a sealed container, they would not decompose. Supporters of spontaneous generation claimed that this was because the heat had changed a property of the air in the container. Pasteur designed experiments to test this claim.

He made a range of flasks, two of which are shown in Figure 12.18, and boiled meat broth in each of them. Fresh air was not prevented from entering the flask, however, it could only enter through a tube, which was designed to stop dust (and microbes) from reaching the liquid. The broths stayed sterile until either the flask was opened or until it was tilted to allow some broth to reach the U-bend and then tipped back again.



▲ **Figure 12.18** Two of Pasteur's flask shapes. The thin tubes allowed air in but microbes were trapped in the U-bend

This series of experiments, and many others, supported the theory that microorganisms *caused* decay and did not appear spontaneously in the liquids.

The germ theory of disease

In 1865, Pasteur was asked to investigate the cause of a disease of silkworms (silk-moth caterpillars) that was destroying the commercial production of silk. He observed that particular microorganisms were present in the diseased caterpillars but not in the healthy ones. He showed that, by removing all of the diseased caterpillars and moths, the disease could be controlled. This evidence supported the idea that the microbes passed from diseased caterpillars to healthy ones, causing the disease to spread.

He broadened this observation to include many forms of transmissible disease, including anthrax. He also persuaded doctors to sterilise their instruments by boiling, and to steam-heat their bandages. In this way, the number of infections that followed surgery was greatly reduced.

Pasteur's discoveries led to the introduction of antiseptic surgery and also to the production of a rabies vaccine.

Revision checklist

After studying Chapter 10 you should know and understand the following:

- ✔ A pathogen is a disease-causing organism.
- ✔ A transmissible disease is one in which the pathogen can be passed from one host to another.
- ✔ Pathogens may be transmitted by direct or indirect contact.
- ✔ The body has defences against pathogens.
- ✔ The mosquito can be a vector of malaria.
- ✔ The malarial pathogen is a parasite which is transmitted by mosquitoes when they feed on blood.
- ✔ Knowledge of the life cycle of the mosquito enables scientists to develop controls to prevent the transmission of malaria.
- ✔ HIV is a viral pathogen, transmitted in several ways.
- ✔ HIV affects the immune system by decreasing lymphocyte numbers and reducing the ability to produce antibodies.
- ✔ HIV infection may lead to AIDS.
- ✔ Cholera is a disease caused by a bacterium that is transmitted in contaminated water.
- ✔ Cholera affects the small intestine, leading to diarrhoea, dehydration and loss of ions from the blood.
- ✔ There are a number of ways of controlling the spread of cholera, including clean water supply, hygienic food preparation, good personal hygiene, waste disposal and sewage treatment.
- ✔ Alcohol is a depressant drug, which slows down reaction time and reduces inhibitions.
- ✔ Smoking and excessive drinking contribute to ill-health.
- ✔ Tobacco smoke affects the gaseous exchange system because it contains toxic components.
- ✔ A drug is any substance taken into the body that modifies or affects chemical reactions in the body.
- ✔ Antibiotics are used in the treatment of bacterial infections.
- ✔ Some bacteria become resistant to antibiotics, which reduces their effectiveness.
- ✔ Antibiotics kill bacteria but not viruses.
- ✔ It is possible to minimise the development of resistant bacteria like MRSA.
- ✔ Active immunity as defence against a pathogen by antibody production in the body.
- ✔ Antibodies are proteins that bind to antigens, which either destroy pathogens directly or mark pathogens for destruction by phagocytes.
- ✔ Each pathogen has its own antigens, which have specific shapes.
- ✔ Antibodies have complementary shapes that fit specific antigens.
- ✔ Active immunity is gained after an infection by a pathogen or by vaccination.
- ✔ The process of vaccination involves the immune response and production of memory cells to give long-term immunity.
- ✔ Vaccination controls the spread of diseases.
- ✔ Passive immunity as a short-term defence against pathogens.
- ✔ Breast-feeding is important for the development of passive immunity in infants.
- ✔ Memory cells are not produced in passive immunity.

Exam-style questions

1 **a** Define the terms
i) *pathogen* [2]
ii) *transmissible disease*. [3]
b Name **three** different groups of organisms that cause disease. [3]
c Describe **two** ways in which pathogens can cause disease. [2]

2 Copy and complete the table using ticks (✔) and crosses (✘) to identify by what method pathogens are transmitted.

vector of pathogen	direct contact	indirect contact
air		
blood		
contaminated surface		
food		
housefly		
semen		

[6]

3 Describe **three** ways that houseflies can transmit bacteria. [3]

4 Explain why people who sell, handle and cook food should be particularly careful about their personal hygiene. [3]

5 Copy the terms and definitions below about diseases and draw straight lines to match each of the terms to its best definition. [4]

Term	Definition
carrier	a disease in which the pathogen can be passed from one host to another
pathogen	a poison which can be produced by some bacteria
toxin	a disease-causing organism
transmissible disease	a person who carries pathogens without showing any signs of the disease

6 State **three** ways by which the body defends itself against pathogens. [3]

7 Explain the differences between active immunity and passive immunity. [6]

8 **a** Describe **three** forms of vaccine. [3]
b Explain how a vaccination works. [3]

9 Suggest why a pregnant woman should neither smoke nor have unprotected sexual contact with a man with HIV. [3]

10 **a** Define the term *drug*. [2]
b What are antibiotics used for? [1]

11 A patient with a viral infection asked the doctor for antibiotics. Explain why the doctor would not prescribe antibiotics for this infection. [1]

12 Explain why doctors are concerned about the over-use of antibiotics. [2]

13 Explain how using antibiotics only when essential can limit the development of resistant bacteria like MRSA. [2]

14 Outline how resistant strains of bacteria can develop. [4]

13 Excretion

Focus

In Chapter 10 you learned that metabolic activities in the body produce waste products that need to be removed. After studying Chapter 9 you will have gained an understanding of how the process of breathing removes carbon dioxide. This is called excretion. What role do the kidneys have in getting rid of potentially toxic waste products? What needs to stay in the blood? What part does the liver play? Chapter 13 explores the excretory process.

FOCUS POINTS

- ★ Where in the body are carbon dioxide, urea, excess water and ions excreted?
- ★ Where in the body are the kidneys, ureters, bladder and urethra?
- ★ What is the structure of the kidney?
- ★ What is the structure and function of the nephron?
- ★ Why is excretion important?
- ★ How is urine formed?
- ★ How is urea formed?
- ★ What is the role of the liver?

Excretion

Key definitions

Excretion is the removal of toxic materials and the waste products of metabolism from organisms.

Excretory materials include

- the waste products of its chemical reactions
- the excess water and ions taken in with the diet
- hormones not able to be used again.

Excretion also includes the removal of drugs or other foreign substances taken into the alimentary canal and absorbed by the blood.

Many chemical reactions take place inside the cells of an organism in order to keep it alive. Some products of these reactions are poisonous and must be removed from the body. For example, the breakdown of glucose during aerobic respiration (see 'Aerobic respiration' in Chapter 10) produces carbon dioxide. This is carried away by the blood and removed in the lungs. Excess amino acids are deaminated in the liver to form glycogen and urea. The urea is removed from the tissues by the blood and expelled by the kidneys.

Urea and similar waste products from the breakdown of proteins contain the element nitrogen. For this reason, they are often called **nitrogenous waste products**.

During feeding, more water and ions are taken in with the food than are needed by the body. So, these excess substances need to be removed as fast as they build up.

The hormones produced by the **endocrine glands** (Chapter 14) affect the rate at which various body systems work. Adrenaline, for example, speeds up the heartbeat. When hormones have done their job, they are changed in the liver and excreted by the kidneys.

The nitrogenous waste products, excess ions and spent hormones are excreted by the kidneys as a watery solution called **urine**.

Going further

Metabolism

All the chemical changes taking place inside a cell or a living organism are called its metabolism. The minimum amount of energy needed just to keep an organism alive, without movement or growth, is called the basal metabolism. Our basal metabolism maintains vital processes like breathing, heartbeat, digestion and excretion.

The processes that break substances down are called catabolism. Respiration is an example of catabolism in which carbohydrates are broken down to carbon dioxide and water. Chemical reactions that build up substances are called anabolism. One example of anabolism is building up a protein from amino acids. The energy released by the process of respiration is used to drive the reactions that build up proteins.

You may have heard of steroids in connection with drug taking by athletes. These chemicals reduce the rate of protein breakdown and may boost the build-up of certain proteins. However, their effects are complicated and not fully understood, they have undesirable side-effects and their use breaks athletics codes.

Excretory organs

Lungs

The lungs supply the body with oxygen, but they are also excretory organs because they get rid of carbon dioxide. Carbon dioxide is a waste product of aerobic respiration (see Chapter 10). They also lose a lot of water vapour, however, this loss is unavoidable and is not a method of controlling the water content of the body (Table 13.1).

Kidneys

The kidneys remove urea and other nitrogenous waste from the blood. They also take out excess water, ions, hormones (Chapter 14) and drugs.

Liver

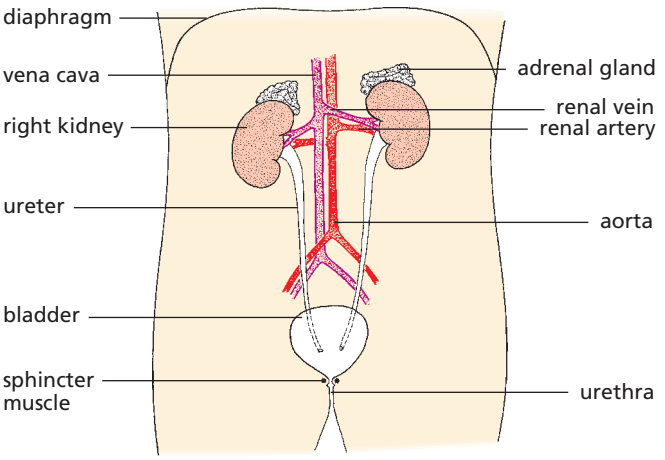
The liver breaks down excess amino acids and produces urea.

▼ **Table 13.1** Excretory products

Excretory organ	Excretory products
lungs	carbon dioxide
kidneys	urea and other nitrogenous waste, water, ions, toxins, hormones, drugs

The kidneys

The two kidneys are quite solid, oval structures. They are red-brown, surrounded by a transparent membrane and attached to the back of the abdominal cavity (Figure 13.1). The renal artery branches off from the aorta and brings oxygenated blood to them. The renal vein takes deoxygenated blood away from the kidneys to the vena cava (see Figure 11.17). A tube, called the **ureter**, runs from each kidney to the **bladder** in the lower part of the abdomen.



▲ **Figure 13.1** Position of the kidneys in the body

Table 13.2 summarises the functions of parts of the urinary system.

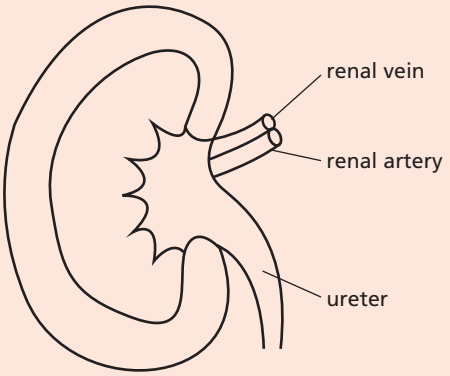
▼ **Table 13.2** Functions of parts of the urinary system

Part	Function
kidneys	the removal of urea and excess water and salt from the blood as urine
ureters	transport urine from the kidneys to the bladder
bladder	stores urine, allowing urination to be controlled
urethra	transports urine from the bladder out of the body

Test yourself

1 Write a list of the substances that are likely to be excreted from the body during the day.

2 Figure 13.2 shows a section through a kidney.



▲ **Figure 13.2** Section through a kidney

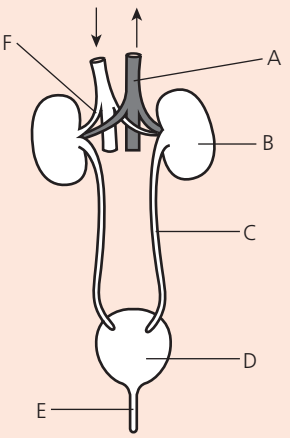
In a healthy person, which of the labelled parts transport glucose?

A renal artery only
B renal artery and renal vein
C renal artery and ureter
D renal vein and ureter

3 What biochemical test could be carried out to find out if a patient has glucose in his urine?

A iodine solution test
B biuret test
C Benedict's test
D oil emulsion test

4 Figure 13.3 shows the excretory system of a human.



▲ **Figure 13.3** Human excretory system

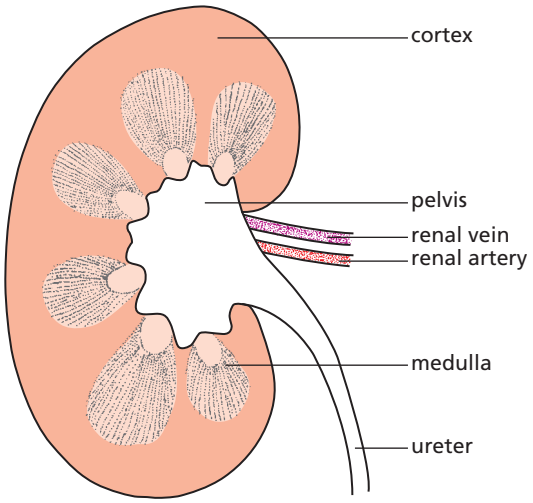
a Name parts A–F.
b For each part, state its function.

The need for excretion

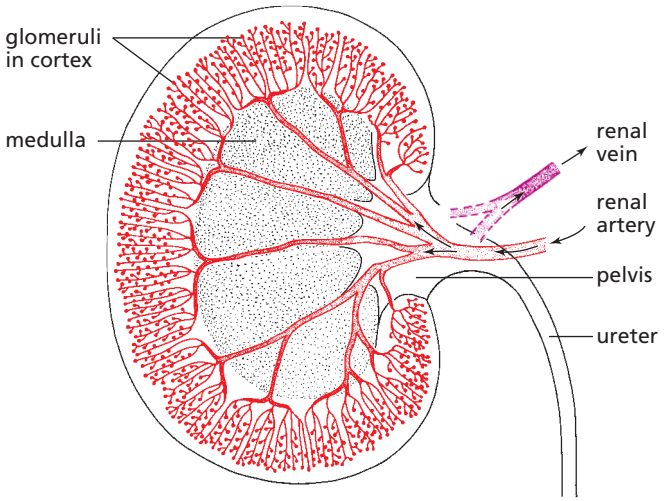
Some of the compounds made in reactions in the body can be toxic (poisonous) if their concentrations build up. For example, ammonia is made in the liver when excess amino acids are broken down. However, ammonia is very alkaline and toxic. It is converted to urea. Urea is much less poisonous than ammonia, so it is a safe way of excreting excess nitrogen.

Microscopic structure of the kidneys

The kidney tissue contains many capillaries and tiny tubes, called **renal tubules**. If the kidney is cut down its length, this exposes a dark, outer region called the **cortex** and a lighter, inner zone, the **medulla**. Where the ureter joins the kidney there is a space called the pelvis (Figure 13.4).



▲ **Figure 13.4** Section through the kidney to show regions



▲ **Figure 13.5** Section through kidney to show distribution of glomeruli

The renal artery divides up into many arterioles and capillaries, mostly in the cortex (Figure 13.5). Each arteriole leads to a glomerulus, which is a network of capillaries (Figure 13.6). Each glomerulus is surrounded by a cup-shaped structure called a **Bowman's capsule**. This leads to a coiled renal tubule. The tubule joins a **collecting duct**, which passes through the medulla to open into the pelvis (Figure 13.6). There are thousands of glomeruli in the kidney cortex and the total surface area of their capillaries is very large.

A **nephron** is a single glomerulus with its Bowman's capsule, renal tubule and blood capillaries (see Figure 13.6).

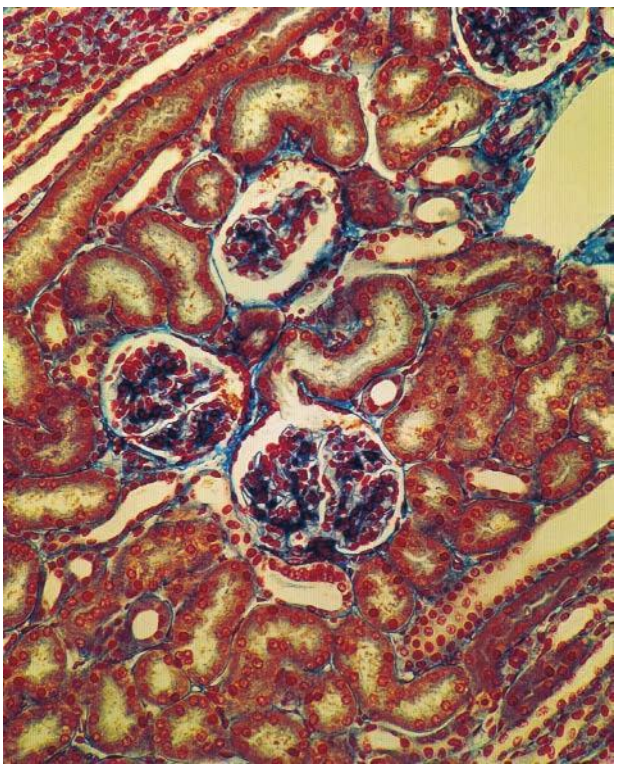
Function of the kidneys

Filtration

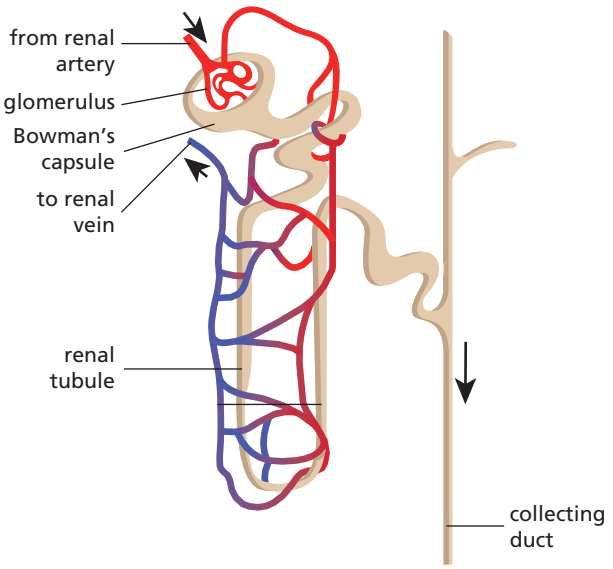
The blood pressure in a glomerulus causes part of the blood plasma to leak through the capillary walls. The red blood cells and the plasma proteins are too big to pass out of the capillary. So, the fluid that does filter through is plasma without the protein, i.e. like tissue fluid (Chapter 11). The fluid consists mainly of water with dissolved ions, glucose and urea.

Reabsorption

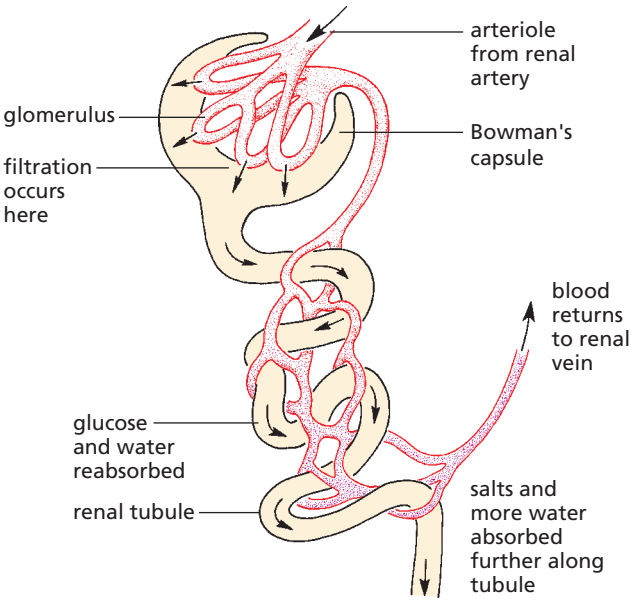
The filtrate from the glomerulus collects in the Bowman's capsule and passes down the renal tubule (Figure 13.8). As it does this, the capillaries that surround the tubule absorb those substances which the body needs back into the blood. First, all the glucose is reabsorbed, with a lot of the water. Then some of the ions are taken back to keep the correct concentration in the blood.



▲ **Figure 13.6** Glomeruli in the kidney cortex (×300). The three glomeruli are surrounded by kidney tubules sectioned at different angles. The light space around each glomerulus is the Bowman's capsule



▲ **Figure 13.7** There are up to 4 million nephrons in a kidney. Only one is shown here, and not to scale



▲ **Figure 13.8** Part of a nephron (glomerulus, Bowman's capsule and renal tubule)

Formation of urine

Urea, water and ions not needed by the body pass down the kidney tubule into the pelvis of the kidney. From here the fluid, now called urine, passes down the ureter to the bladder.

Table 13.3 shows some of the differences between the contents of blood plasma and urine. The figures represent average values because urine varies depending on diet, activity, temperature and intake of liquid.

▼ **Table 13.3** Composition of blood plasma and urine

	Plasma/%	Urine/%
water	90–93	95.0
urea	0.03	2.0
ammonia	0.0001	0.05
sodium	0.3	0.6
potassium	0.02	0.15
chloride	0.37	0.6
phosphate	0.003	0.12

The bladder can expand to hold about 400 cm^3 of urine. The urine cannot escape from the bladder because a band of circular muscle, called a **sphincter**, is contracted. This shuts off the exit. When this sphincter muscle relaxes, the muscular walls of the bladder expel the urine through the urethra. Adults can control this sphincter muscle and relax it only when they want to urinate. In babies, the sphincter relaxes by a reflex action (Chapter 14), set off by pressure in the bladder. By 3 years old, most children can control the sphincter voluntarily.

The liver and its role in producing proteins

As well as being an excretory organ, the liver plays a very important role in assimilating amino acids. Assimilation means the absorption of substances, which are then built into other compounds in the organism (see Chapter 8). The liver removes amino acids from the plasma of the bloodstream and builds them up into proteins. Proteins are long chains of amino acids joined together by peptide bonds (see Chapter 4 for details of protein structure). These include plasma proteins like fibrinogen (Chapter 11), which have a role in blood clotting.

The liver and its role in dealing with excess amino acids

Key definitions

Deamination is the removal of the nitrogen-containing part of amino acids to form urea.

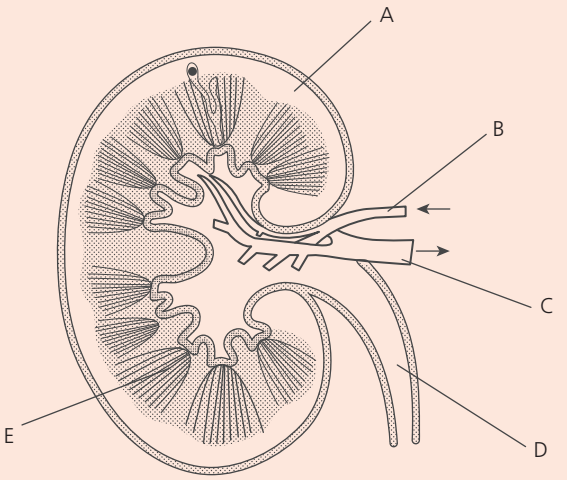
Unlike surplus glucose and fats, excess amino acids cannot be stored in the body. They are broken down by the liver, removing the nitrogen-containing part to form ammonia. The rest of the molecule can be converted into carbohydrates and lipids and used in respiration. The ammonia is converted to urea. This passes into the bloodstream and is filtered out by the kidneys. This process is called deamination.

Test yourself

5 The nephrons of the kidney filter substances out of the blood. Which substances are reabsorbed back into the blood?
   A glucose and water
   B protein and water
   C protein and glucose
   D urea and water

6 Figure 13.9 shows a section through a kidney.
   a Name parts A–E.
   b **i)** Name the fluid present in part D
   ii) State the contents of the fluid in part D.
   c State three differences in the contents of blood vessels B and C.
   d Name and describe what structures would be found in part A.

7 Study Table 13.3. The bladder can hold 400 cm^3 of urine. Calculate what volume of water will be present in the urine when the bladder is full.



▲ **Figure 13.9** Section through a kidney

Revision checklist

After studying Chapter 13 you should know and understand the following:

- ✔ The definition of excretion.
- ✔ The lungs excrete carbon dioxide.
- ✔ The parts of the urinary system.
- ✔ The kidneys excrete urea, excess water and unwanted ions.
- ✔ The structure of the kidney.
- ✔ The structure and function of a nephron.
- ✔ Part of the blood plasma entering the kidneys is filtered out by the capillaries. Substances that the body needs, like glucose, are absorbed back into the blood. The unwanted substances are left to pass down the ureters into the bladder.
- ✔ The bladder stores urine, which is discharged at intervals.
- ✔ The kidneys help to keep the blood at a steady concentration by excreting excess ions and by adjusting the amounts of water.
- ✔ Deamination is the removal of the nitrogen-containing part of amino acids to form urea.
- ✔ The liver has a role in the assimilation of amino acids by converting them to proteins.

Exam-style questions

1 a Define the term *excretion*. [3]

b Describe the roles of

i) the kidneys in excretion [3]

ii) the lungs in excretion. [1]

c Two of the tubes associated with the urinary system are the ureter and the urethra.

i) What do they have in common? [1]

ii) Distinguish between the two tubes. [2]

2 a State the names of the four excretory materials. For each material, state which organ removes it from the blood. [8]

b Distinguish between excretion and egestion. [4]

3 a Explain how the composition of urine would change

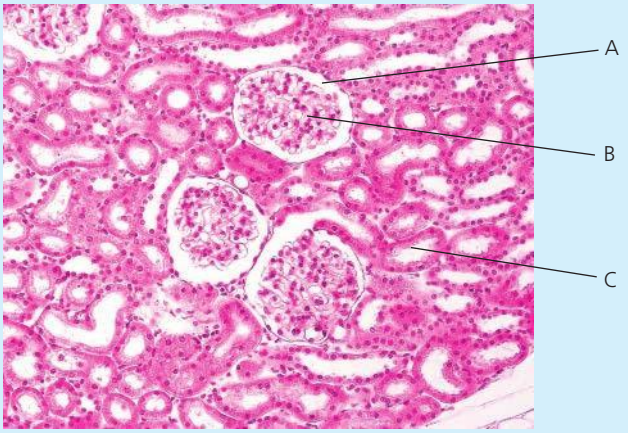
i) in a healthy person after eating meat [3]

ii) in a diabetic after eating a large meal without taking any insulin. [3]

b Describe the role of the liver when levels of amino acids in the blood are high. [3]

4 Describe the passage of water from its presence in blood in the aorta to its excretion as urine. [6]

5 The photomicrograph shows a section through the cortex of a kidney.



a Name parts A and B. [2]

b Part C identifies a kidney tubule cut in transverse section. The epithelium of the tubule is covered by microvilli.

i) State the meaning of the term *epithelium*. [1]

ii) Suggest why the epithelium of the tubule is covered by microvilli. [2]

c The tissue surrounding the tubule contains a high concentration of ions. Suggest how this will help the process of reabsorption. [3]

d The diameter of structure B in the photomicrograph is 15 mm. Its actual diameter was 150 μm.
Calculate the magnification of the photomicrograph. [3]

14 Coordination and control

Focus

All the topics we have studied so far have involved coordination in some way. It may be coordinating all the systems in a whole organism, or even microscopic structures such as the nephron in a kidney. This may be achieved by means of electrical impulses passing through the nervous system or by means of chemicals called hormones, produced by the endocrine system. Both generate responses. This chapter will explore how these two systems work in animals; the nervous system and endocrine system.

Coordination and response

FOCUS POINTS

- ★ How do impulses travel along neurones?
- ★ What are the central nervous system and the peripheral nervous system?
- ★ What is the role of the nervous system?
- ★ What are the differences between sensory, relay and motor neurones?
- ★ What is a simple reflex arc, a reflex action and a synapse?
- ★ What is the structure of a synapse and what happens there?
- ★ What is an important function of synapses?

Coordination is the way all the organs and systems of the body are made to work efficiently together (Figure 14.1). If, for example, the leg muscles are being used for running, they will need extra supplies of glucose and oxygen. To meet this demand, the lungs and heart respond. The lungs breathe faster and deeper to obtain the extra oxygen and the heart pumps more rapidly to get the oxygen and glucose to the muscles more quickly.

The brain detects changes in the oxygen and carbon dioxide content of the blood and sends nervous impulses to the diaphragm, intercostal muscles and heart. In this example, the nervous system coordinates the systems and regulates body functions.

It works by sending electrical impulses along nerves.

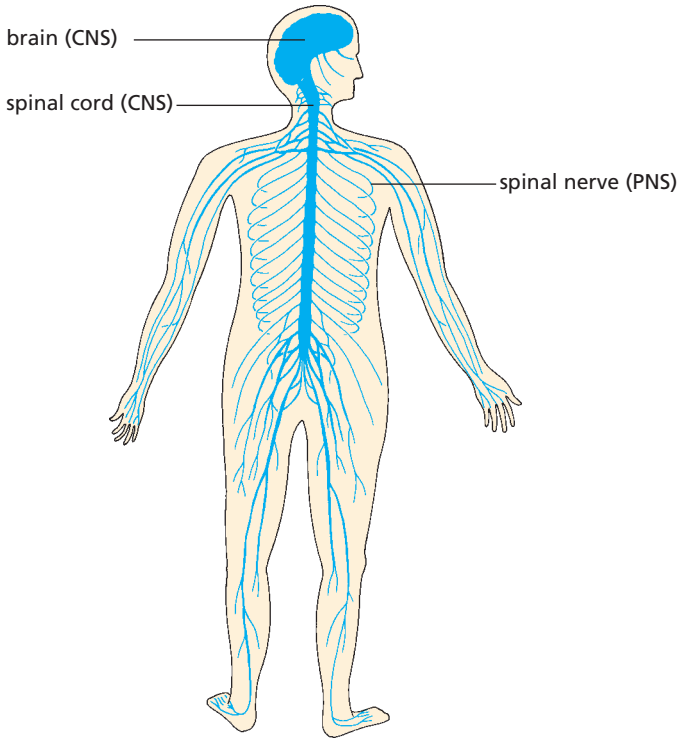
▲ **Figure 14.1** Coordination. The badminton player's brain is receiving sensory impulses from his eyes, ears (sound and balance) and muscle stretch receptors. Using this information, the brain coordinates the muscles of his limbs so that even while running or leaping he can control his stroke

Nervous control in humans

The human nervous system is shown in Figure 14.2. The brain and spinal cord together form the central nervous system (CNS). Nerves carry electrical impulses from the central nervous system to all parts of the body, making muscles contract or stimulating glands to produce enzymes or hormones. Electrical impulses are electrical signals that pass along nerve cells (**neurones**).

Glands and muscles are called **effectors** because they act when they receive nerve impulses or hormones. The biceps muscle is an effector that flexes the arm. The salivary gland (see 'Human digestive system' in Chapter 8) is an effector that secretes saliva when it receives a nerve impulse from the brain.

The nerves also carry impulses back to the central nervous system from receptors in the sense organs of the body. These impulses from the eyes, ears, skin, etc. make us aware of changes in our surroundings or in ourselves. Nerve impulses from the sense organs to the central nervous system are called *sensory impulses*. Those from the central nervous system to the effectors, resulting in a response, are called *motor impulses*.



▲ **Figure 14.2** The human nervous system

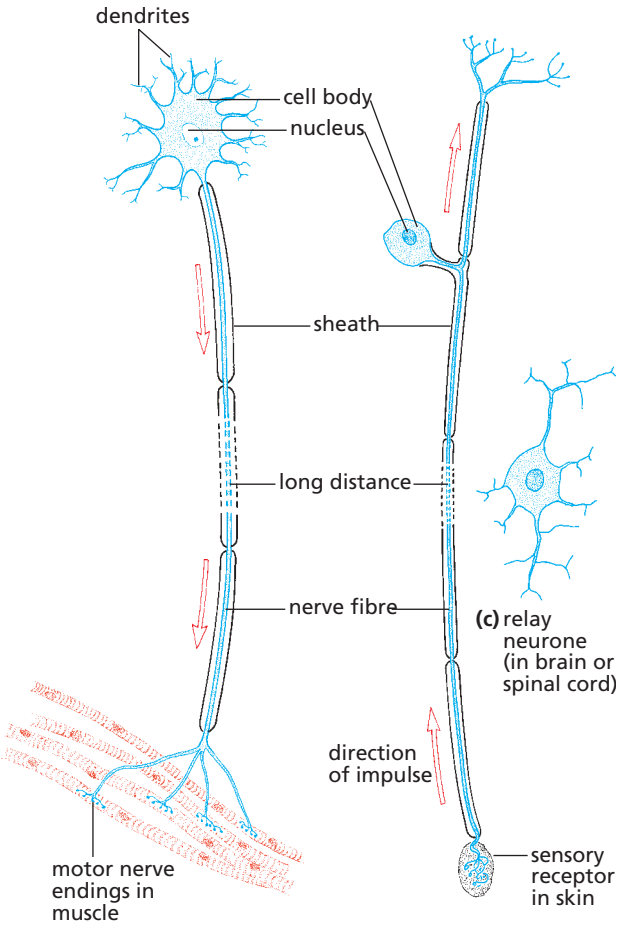
The nerves, outside the brain and spinal cord, that connect the body to the central nervous system make up the **peripheral nervous system (PNS)**.

Nerve cells (neurones)

The central nervous system and the peripheral nerves are made up of nerve cells called neurones. Three types of neurone are shown in Figure 14.3. **Motor neurones** (also called effector neurones) carry impulses from the central nervous system to muscles and glands. **Sensory neurones** carry impulses from the sense organs to the central nervous system.

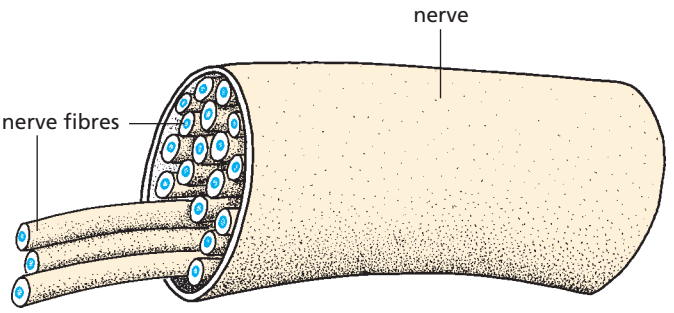
Relay neurones (also called connector or multipolar neurones) are neither sensory nor motor. They make connections to other neurones inside the central nervous system. Junctions where neurones connect with each other are called **synapses**.

Each neurone has a *cell body* consisting of a nucleus surrounded by cytoplasm. *Dendrites* are fibres, which branch from the cell body to make contact with other neurones. A long filament of cytoplasm, surrounded by an insulating sheath, runs from the cell body of the neurone. This filament is called a *nerve fibre* (Figure 14.3(a) and (b)). The cell bodies of the neurones are mostly found in the brain or in the spinal cord. The nerve fibres run in the nerves. A *nerve* is easy to see. It is white, tough and stringy, and consists of hundreds of microscopic nerve fibres bundled together (Figure 14.4). Most nerves will contain a mixture of sensory and motor fibres, so a nerve can carry many different impulses. These impulses will travel in one direction in sensory fibres and in the opposite direction in motor fibres.



▲ **Figure 14.3** Nerve cells (neurones)

Some of the nerve fibres are very long. The cell bodies of the nerve fibres are found in the spinal cord. Those fibres connected to the foot run inside the nerves continuously to the skin of the toes or the muscles of the foot. A single nerve cell may have a fibre 1 m long.



▲ **Figure 14.4** Nerve fibres grouped into a nerve

Going further

The nerve impulse

The nerve fibres do not carry sensations like pain or cold. These sensations are only felt when a nerve impulse reaches the brain. The impulse is a series of electrical pulses that travel down the fibre. Each pulse lasts about 0.001 s and travels at speeds of up to 100 m s^{-1}. All nerve impulses are similar; there is no difference between nerve impulses from the eyes, ears or hands.

We know where the sensory impulses have come from and what caused them because the impulses are sent to different parts of the brain. The nerves from the eye go to the part of the brain concerned with sight. So, when impulses are received in this area, the brain recognises that they have come from the eyes and we *see* something.

Test yourself

1 Construct a table to compare sensory, motor and relay neurones.

2 **a** The pulse of a nerve impulse lasts for 0.001 s and travels at a speed of 100 m s^{-1}.
Convert these values for duration of pulse and its speed into standard form.

b Suggest why neurones are sometimes covered by a myelin sheath.

3 **a** State the difference between a nerve and a nerve fibre.

b Explain whether
(i) a nerve fibre and
(ii) a nerve can carry both sensory and motor impulses.

4 **a** Describe the role of the nervous system.

b What do the following parts of the nervous system consist of?
i) Central nervous system.
ii) Peripheral nervous system.

Synapses

Key definitions
A **synapse** is a junction between two neurones.

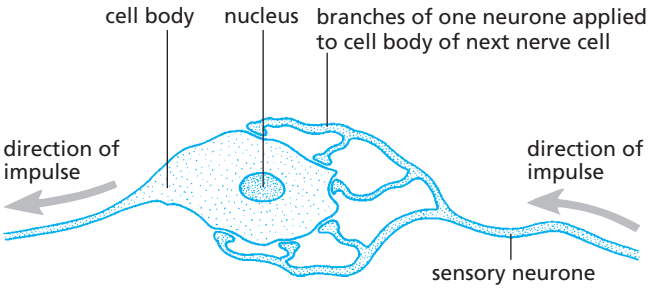
Although nerve fibres are insulated, it is necessary for impulses to pass from one neurone to another. An impulse from the fingertips must pass through at least three neurones before reaching the brain, and so producing a conscious sensation. The regions where impulses can cross from one neurone to the next are called synapses.

How a synapse transmits an electrical impulse

At a synapse, a branch at the end of one fibre is in close contact with the cell body or dendrite of another neurone (Figure 14.5).

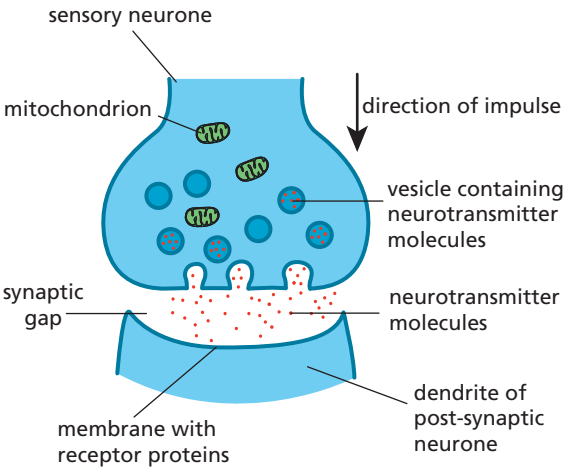
When an impulse arrives at the synapse, **vesicles** in the cytoplasm are stimulated to release a tiny amount of the **neurotransmitter molecules** (Figure 14.6). The molecules rapidly diffuse across the **synaptic gap** and bind with neurotransmitter **receptor proteins** in the membrane of the neurone on the other side of the synapse. This then stimulates

a new impulse in the neurone. Sometimes several impulses need to arrive at the synapse before enough transmitter molecules are released to cause an impulse to be fired off in the next neurone.



▲ **Figure 14.5** Synapses between nerve neurones

Impulses only travel in one direction. Synapses control the direction of impulses because neurotransmitter molecules are only synthesised on one side of the synapse and receptor proteins are only present on the other side. They slow down the speed of nerve impulses slightly because of the time taken for the chemical to diffuse across the synaptic gap.



▲ **Figure 14.6** Structure of a synapse

Going further

Many drugs produce their effects by interacting with receptor molecules at synapses.

Spider toxin and the toxin released by tetanus (an infection caused by *Clostridium* bacteria), breaks down vesicles, releasing massive amounts of transmitter molecules and disrupting normal synaptic function. Symptoms caused by the tetanus toxin include muscle spasms, lock-jaw and heart failure.

The reflex arc

Key definitions

A **reflex action** is a rapid and automatic response to a stimulus.

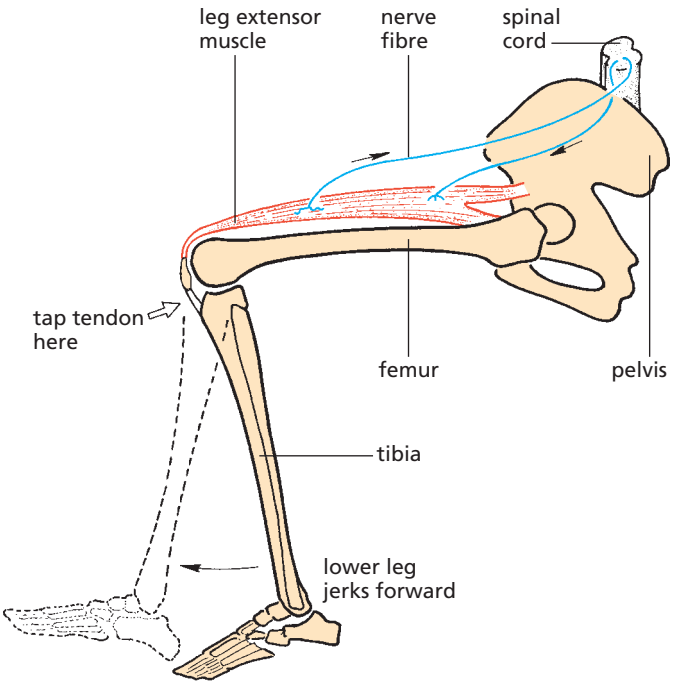
One of the simplest situations where impulses cross synapses to produce action is in the **reflex arc**. A reflex action is a rapid and automatic response to a stimulus. (A stimulus is a change in the external or internal environment of an organism.) It provides a means of linking a stimulus with an effector to get a response of an effector (a muscle or a gland) without the need for thought or a decision. It is automatic. When a particle of dust touches the **cornea** of the eye, you will blink; you cannot stop yourself blinking. A particle of food touching the lining of the windpipe will set off a coughing reflex that you cannot stop. When a bright light shines in the eye, the **pupil** contracts (see 'Sense organs' later in this chapter). You cannot stop this reflex and you are not even aware that it is happening.

The nervous pathway for reflexes like these is called a reflex arc. In Figure 14.7 the nervous pathway for a well-known reflex called the *knee-jerk* reflex is shown.

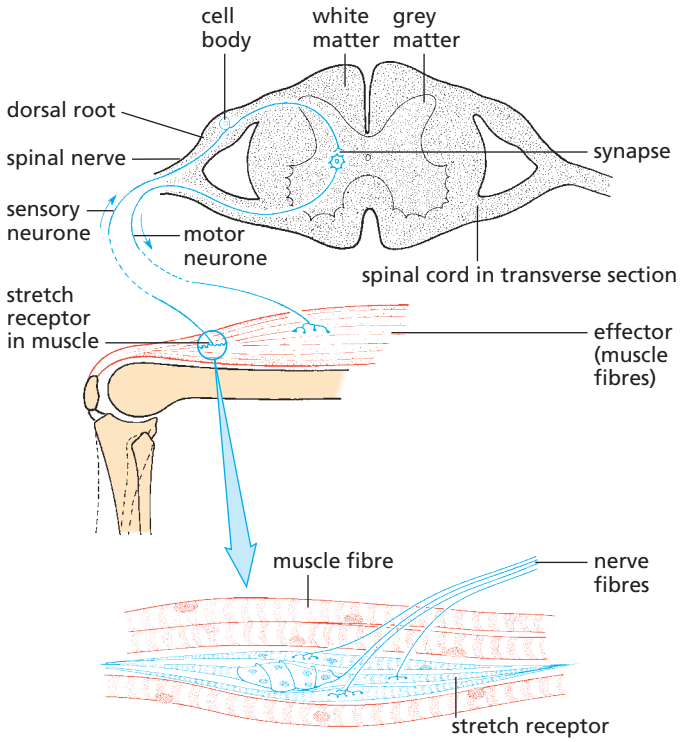
To show this, cross one leg over the other, with the muscles totally relaxed. Get a volunteer to tap the tendon just below the kneecap of your upper leg sharply. A reflex arc will make your thigh muscle contract and the lower part of your leg will swing forward.

The pathway of this reflex arc is shown in Figure 14.8. Hitting the tendon stretches the muscle and stimulates a stretch receptor. The receptor sends off impulses in a sensory fibre. These sensory impulses travel in the nerve to the spinal cord.

In the central region of the spinal cord, the sensory fibre passes the impulse across a synapse to a motor neurone. This conducts the impulse down the fibre, back to the thigh muscle (the effector). When the impulses reach the muscle they make it contract and jerk the lower part of the limb forward. You are aware that this is happening (which means that sensory impulses must be reaching the brain), but there is nothing you can do to stop it.



▲ **Figure 14.7** The knee-jerk reflex



▲ **Figure 14.8** The reflex arc. This reflex arc only needs one synapse for making the response. Most reflex actions need many more synapses (1) to adjust other muscles in the body and (2) to send impulses to the brain

The sequence of events in a simple reflex arc is shown below.

stimulus (tapping the tendon below the kneecap)
↓
receptor (stretch receptor)
↓
sensory neurone
↓
co-ordinator (spinal cord)
↓
motor neurone
↓
effector (leg extensor muscle)
↓
response (leg extensor muscle contracts, making the leg kick forwards)

Going further

Reflexes

The **iris** reflex is a *spinal reflex*. In theory, the brain is not needed for it to happen. Responses that take place in the head, like blinking, coughing and iris contraction, have their reflex arcs in the brain, but may still not be consciously controlled.

Bright light stimulates the light-sensitive cells of the **retina**. The nerve impulses in the sensory fibres from these receptors travel through the **optic nerve** to the brain. In the mid-brain the fibres synapse with relay and motor fibres. These carry impulses back through the optic nerve to the circular muscle of the iris and stimulate it to contract.

Test yourself

5 Make a mnemonic to remember the sequence of events in a simple reflex arc in the correct order.

6 Put the following in the correct order for a simple reflex arc:
- **A** impulse travels in motor fibre
- **B** impulse travels in sensory fibre
- **C** effector organ stimulated
- **D** receptor organ stimulated
- **E** impulse crosses synapse

The special property of sensory cells and sense organs is that they can convert one form of energy to another. The eyes can transfer light energy into the electrical energy of a nerve impulse. The ears transfer the energy in sound vibrations into nerve impulses. The forms of energy that make up the stimuli can be very different, for example, mechanical, chemical, light, but they are all transferred into pulses of electrical energy in the nerves.

When a receptor responds to a stimulus, it sends a nerve impulse to the brain, which makes us aware of the sensation.

Sense organs

FOCUS POINTS

- ★ What is a sense organ?
- ★ What are the parts of the eye and their functions?
- ★ What is the pupil reflex?
- ★ How does the pupil reflex work?
- ★ How does the eye accommodate near and distant objects?
- ★ Where are rods and cones found in the retina and what are their functions?
- ★ Where is the fovea and what is its function?

Key definitions

Sense organs are groups of receptor cells responding to specific stimuli, such as light, sound, touch, temperature and chemicals.

The eye

Note: Details of functions of sclera, conjunctiva, humours, choroid and tear glands are not a syllabus requirement. However, they are included here to put parts seen in a diagram of the eye in context.

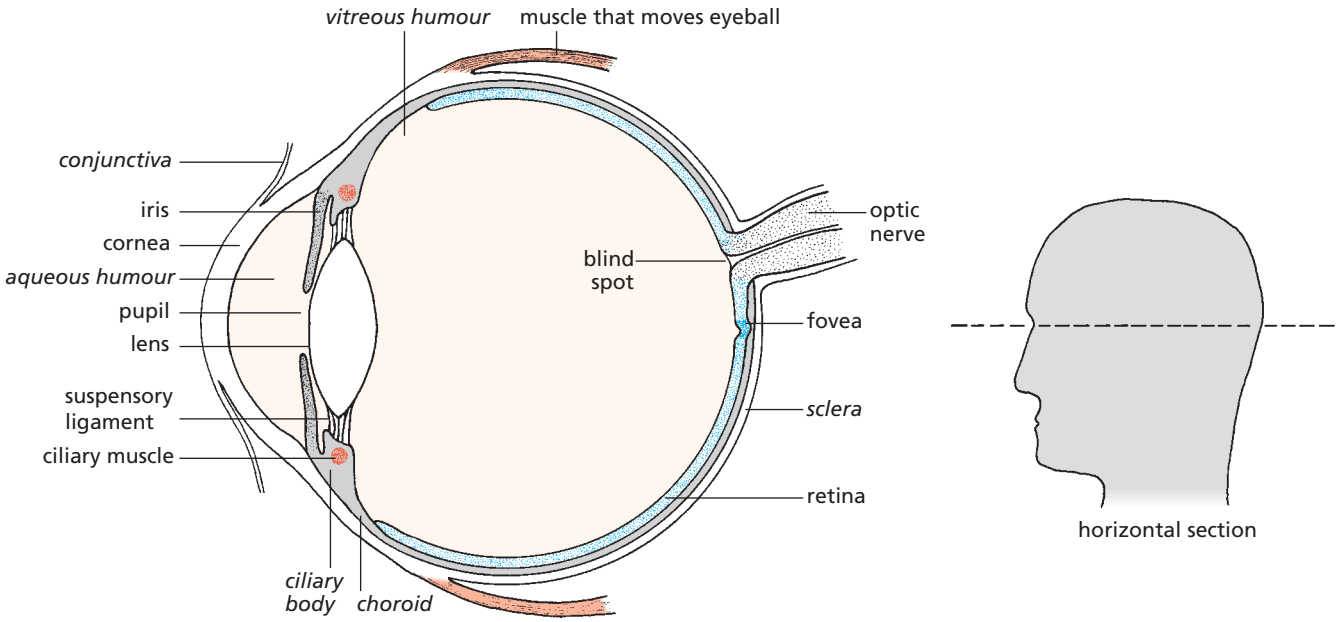
The structure of the eye is shown in Figures 14.9 and 14.10. The *sclera* is the tough, white outer coating. The front part of the sclera is clear and allows light to enter the eye. This part is called the cornea. The conjunctiva is a thin epithelium, which lines the inside of the eyelids and the front of the sclera.

The eye contains a clear liquid, which puts pressure on the sclera, keeping the spherical shape of the eyeball. The liquid behind the lens is jelly-like and called vitreous humour. The aqueous humour in front of the lens is watery.

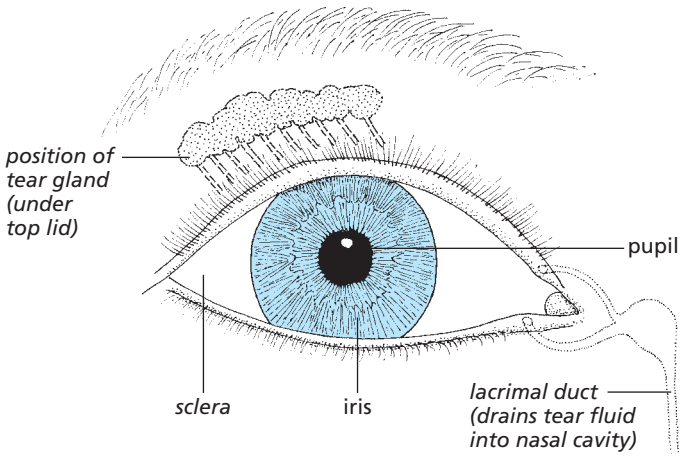
The **lens** is a transparent structure held in place by a ring of fibres called the **suspensory ligament**. Unlike the lens of a camera or a telescope, the eye lens is flexible and can change its shape. In front of the lens is a disc of tissue called the iris. When we describe the colour of the eye as brown or blue, we are really referring to the iris. The iris controls how much light enters the pupil, which is a hole in the centre of the iris. The pupil lets in light to the rest of the eye.

The pupil looks black because all the light entering the eye is absorbed by the black pigment in the choroid. The choroid layer lies between the retina and the sclera, and contains many blood vessels. In the front of the eyeball, it forms the iris and the **ciliary body**. The ciliary body produces aqueous humour and contains **ciliary muscles**, which control the thickness of the lens.

The internal lining at the back of the eye is the retina and it consists of many thousands of cells that respond to light. When light falls on these cells, they send off nervous impulses, which travel in nerve fibres, through the optic nerve to the brain, resulting in the sensation of sight. The part of the retina lying directly in front of the optic nerve is called the blind spot (Figure 14.9). It contains no light-sensitive cells, so no information reaches the brain about the part of the image that falls here.



▲ **Figure 14.9** Horizontal section through left eye



▲ **Figure 14.10** Appearance of right eye from the front

▲ **Figure 14.11** The blind spot. Hold the book about 50 cm away. Close your left eye and concentrate on the cross with your right eye. Slowly bring the book closer to your face. When the image of the dot falls on the blind spot it will seem to disappear

The retina contains light-sensitive cells. Some of these are sensitive to light of various colours and others form images in shades of grey. Cone cells are concentrated in one part of the retina called the **fovea**. These cells detect coloured light.

Tear glands under the top eyelid produce tear fluid. This is a dilute solution of sodium chloride and sodium hydrogencarbonate. The fluid is spread over the eye surface by the blinking of the eyelids. This keeps the surface moist and washes away any dust particles or foreign bodies. Tear fluid also contains an enzyme, lysozyme, which attacks bacteria.

Table 14.1 gives the functions of the parts of the eye required for the syllabus.

▼ **Table 14.1** Functions of parts of the eye

Part	Function
cornea	a transparent, curved layer at the front of the eye that **refracts** the light entering and helps to focus it
iris	a coloured ring of circular and **radial muscle** that changes the size of the pupil, controlling how much light enters the pupil
lens	a transparent, convex, flexible, jelly-like structure that refracts light to focus it onto the retina
retina	a light-sensitive layer made up of rods, which detect light of low intensity, and cones, which detect different colours
optic nerve	transmits electrical impulses from the retina to the brain
ciliary muscles	the muscles form a circular band around the lens and are involved in controlling the shape of the lens
suspensory ligaments	the suspensory ligaments link the muscles to the lens and are also involved in controlling the shape of the lens
fovea	a central part of the retina where cone cells are most concentrated to detect coloured light

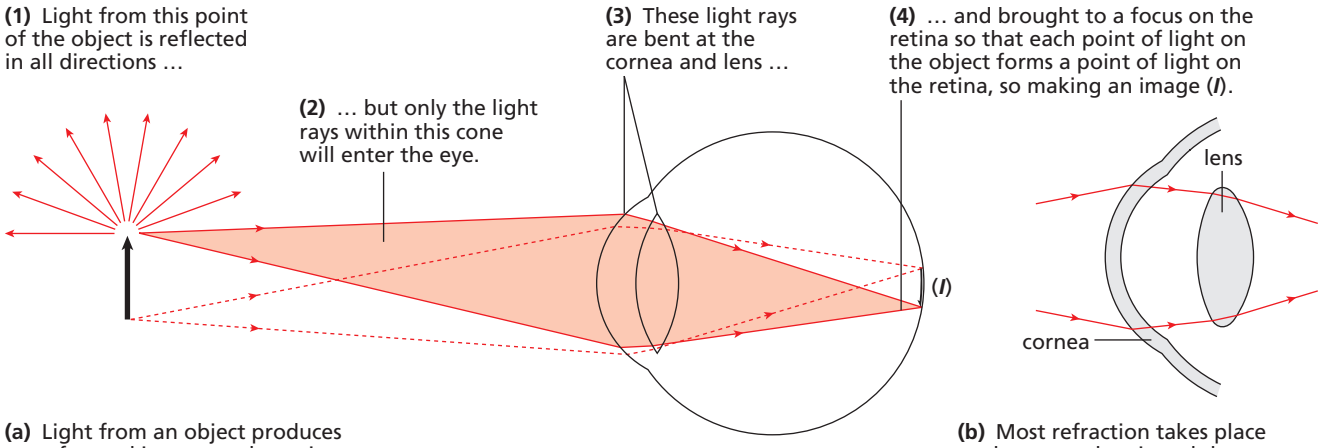
Going further

Vision

Light from an object produces a focused image on the retina (like a picture on a cinema screen) (Figures 14.12 and 14.16). The curved surfaces of the cornea and lens both refract (bend) the light rays that enter the eye, so that each point of light from the object forms a point of light on the retina. These points of light will form an image, upside-down and smaller than the object.

The cornea and the aqueous and vitreous humours are mainly responsible for the refraction of light. The lens makes the final adjustments to the focus (Figure 14.12(b)).

The pattern of sensory cells stimulated by the image will produce a pattern of nerve impulses sent to the brain. The brain interprets this pattern, using past experience and learning, and forms an impression of the size, distance and upright nature of the object.



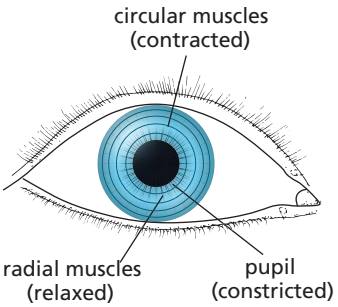
(a) Light from an object produces a focused image on the retina.

(b) Most refraction takes place between the air and the cornea.

▲ **Figure 14.12** Image formation on the retina

The pupil reflex

The change in size of the pupil is caused by exposure of the eye to different light intensities (Figure 14.13). If the light intensity is high, it causes a contraction in a ring of muscle fibres (circular muscle) in the iris. This reduces the size of the pupil and cuts down the intensity of light entering the eye. High-intensity light can damage the retina, so this reaction has a protective function.



▲ **Figure 14.13** The iris reflex

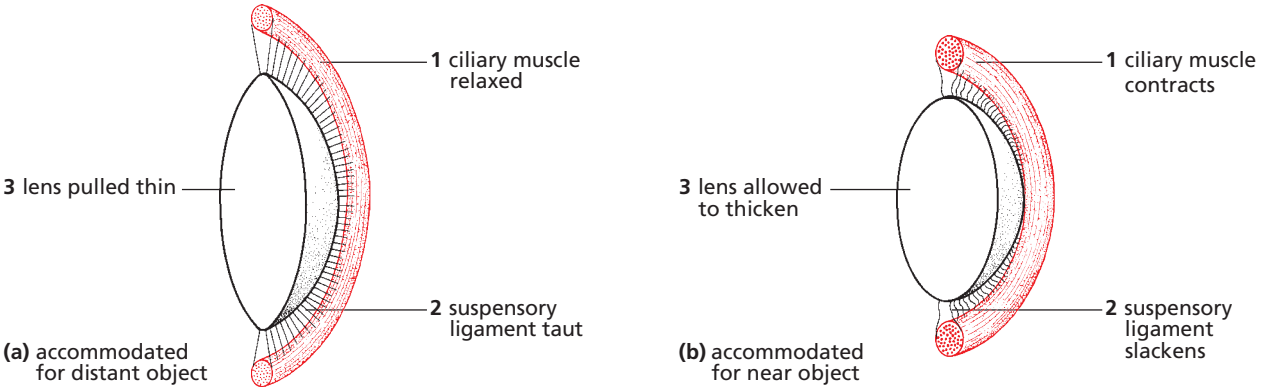
In low light intensities, the circular muscle of the iris relaxes and radial muscle fibres (which are arranged like the spokes of a bicycle wheel) contract. This makes the pupil enlarge and allows more light to enter. The circular and radial muscles act **antagonistically**. This means that they oppose each other in their actions – when the circular muscles contract, they constrict the pupil and when the radial muscles contract the pupil dilates.

The change in size of the pupil is caused by an automatic reflex action; you cannot control it consciously.

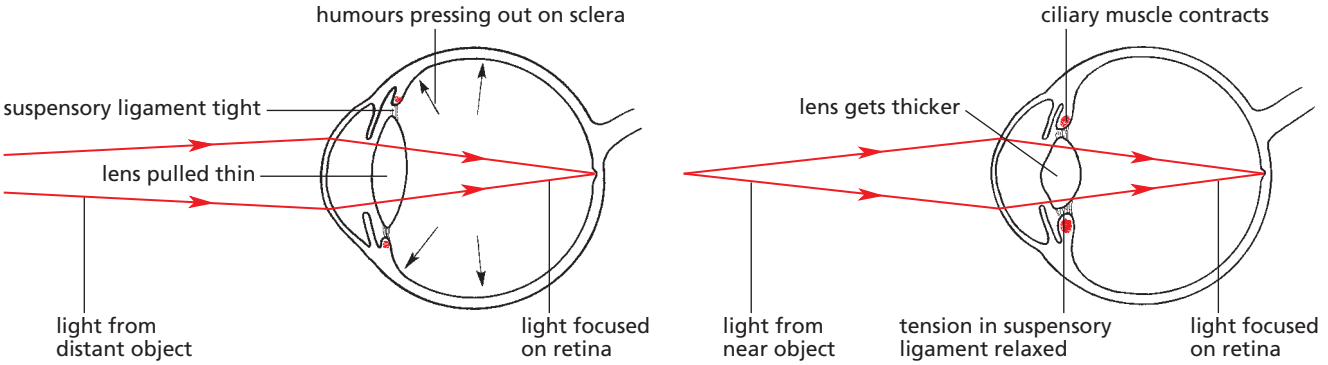
Accommodation (focusing)

The eye can produce a focused image of either a near object or a distant object. To do this the lens changes its shape, becoming thinner for distant objects and fatter for near objects. This change in shape is caused by contracting or relaxing the ciliary muscle, which forms a circular band of muscle in the *ciliary body* (Figure 14.14). When the ciliary muscle is relaxed, the outward pressure of the humours on the *sclera* pulls on the suspensory ligament. This stretches the lens to its thin shape so it refracts light less. The eye is now **accommodated** (i.e. focused) for distant objects

(Figures 14.14(a) and 14.15(a)). To focus a near object, the ciliary muscle contracts to a smaller circle and this takes the tension out of the suspensory ligament (Figures 14.14(b) and 14.15(b)). The lens is elastic and flexible and so it can change to its fatter shape. This shape refracts light more and is better at bending the light rays from a close object.



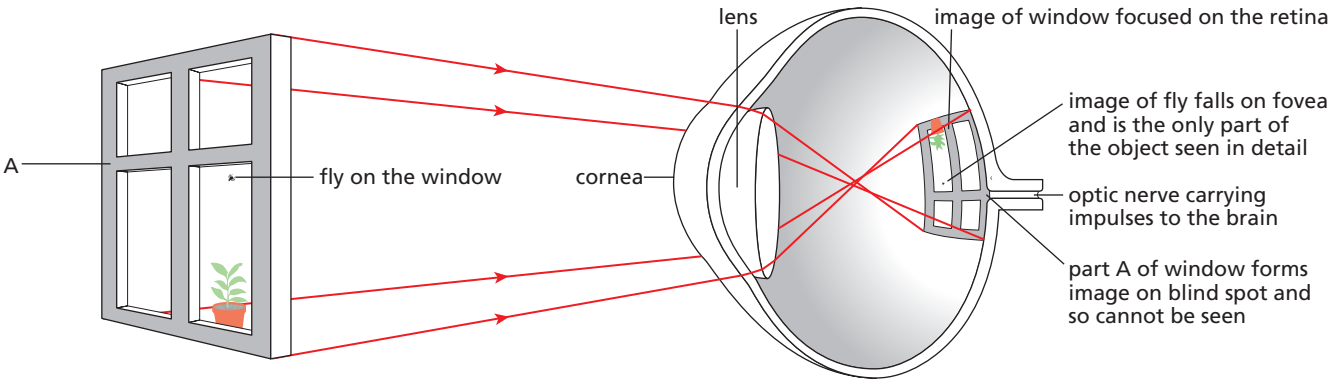
▲ **Figure 14.14** How accommodation is brought about



(a) accommodated for distant object

(b) accommodated for near object

▲ **Figure 14.15** Accommodation



▲ **Figure 14.16** Image formation in the eye

Practical work

1 Observing the pupil reflex

You will need a bench lamp, small ruler and small mirror.

- Work in a darkened room.
- Allow your eyes to adjust to the darkness.
- Hold the ruler close to one eye and use the mirror to allow you to see your pupil. Measure the diameter of your pupil in millimetres.
- While still holding the mirror, switch on the bench lamp so it shines into your eye.
- Observe your pupil as it changes size.
- Measure the new diameter of your pupil.

Results

In the dark, your pupil will look big and its diameter will be about 10 mm.

When it is exposed to the bright light, it will rapidly get smaller. Its final diameter will be as little as 2 mm.

Interpretation

In the dark your pupil will become as large as possible to let the maximum amount of light into your eye. In the bright light the pupil shrinks to limit the amount of light falling on the retina in order to protect it.

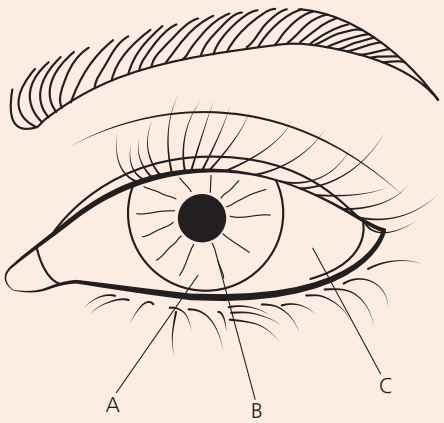
Practical work questions

1 The area around the pupil is called the iris.
- **a** What colour is your iris?
- **b** What colour does your pupil appear to be?

2 **a** Calculate the percentage decrease in size of your pupil when it is exposed to bright light. (Use figures from the practical if you do not have your own.)
- **b** Suggest what would happen to the size of your pupil if you turned the light off.

Test yourself

7 Figure 14.17 shows a front view of the eye.

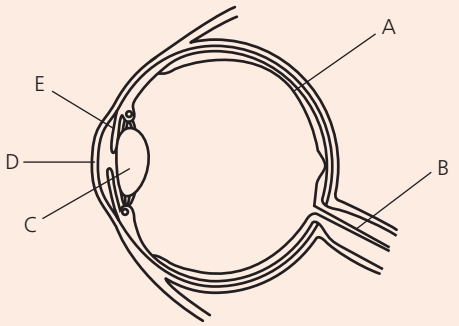


▲ **Figure 14.17** Front view of the eye

- **a** Identify parts A and B.
- **b** State the function of part A.
- **c** Suggest why part B appears to be black.
- **d** Although part C is white, there are blood vessels in it. Suggest the function of these blood vessels.

8 **a** Define the term *sense organ*.
- **b** Name three sense organs other than the eye and state what they detect.

9 Figure 14.18 shows a section through the eye.



▲ **Figure 14.18** Section through the eye

- **a** Identify parts A–E.
- **b** Describe how part C is different from a similar structure found in a camera.
- **c** Suggest the effect of part B becoming damaged.

Hormones

FOCUS POINTS

- ★ What is a hormone?
- ★ Where are hormones made?
- ★ Which gland secretes glucagon?
- ★ When is adrenaline secreted and what are its effects on the body?
- ★ What is the role of adrenalin in the control of metabolic activity?
- ★ What are the differences between nervous and hormonal control?

Key definitions

A **hormone** is a chemical substance, produced by a gland and carried by the blood, which alters the activity of one or more specific target organs.

Coordination by the nervous system is usually rapid and precise. Nerve impulses, travelling at up to 100 metres per second, are delivered to specific parts of the body and produce an almost immediate response. A different kind of coordination is brought about by the **endocrine system**. This system depends on chemicals, called hormones, which are released into the bloodstream from special glands, called endocrine glands.

The hormones circulate around the body in the blood and eventually reach their target organs. Hormones speed up, slow down or alter the activity of those organs. After being secreted, hormones only remain temporarily in the blood. They are changed by the liver into inactive compounds and excreted by the kidneys. **Insulin**, for example, may stay in the bloodstream for just 4–8 hours before being broken down. Table 14.2 compares control by the endocrine and nervous systems.

▼ **Table 14.2** Endocrine and nervous control compared

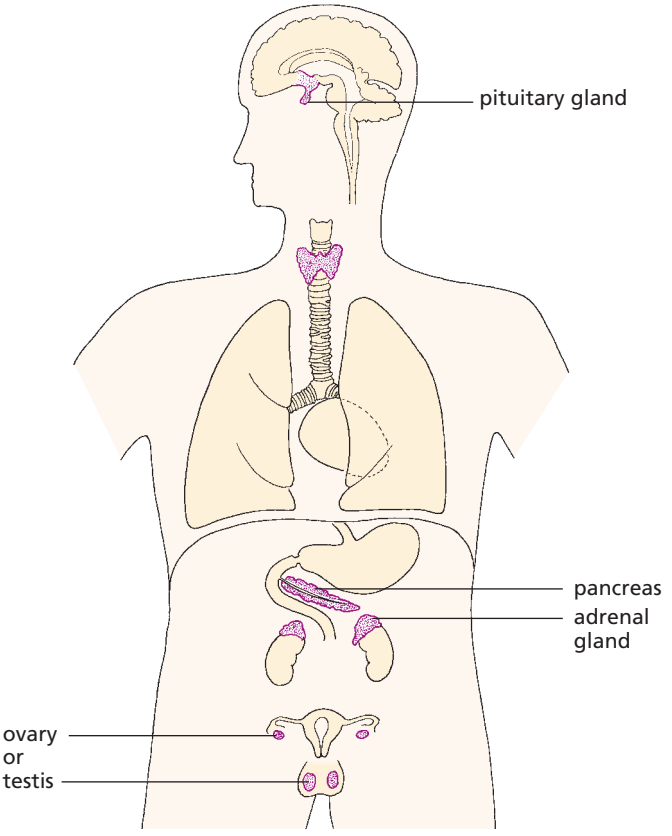
Endocrine	Nervous
transmission of chemicals	transmission of electrical impulses
transmission through blood	transmission in nerves
slow transmission	rapid transmission
hormones dispersed throughout body	impulse sent directly to target organ
long-term effects	short-term effects

Digestive glands deliver their secretions through ducts (tubes). However, endocrine glands do not do this. For this reason, they are sometimes called *ductless glands*. The hormones pass directly from the glands where they are made, into the blood circulation.

Responses of the body to hormones are much slower than responses to nerve impulses. They firstly depend on the speed of the circulatory system and then on the time it takes for the cells to change their chemical activities. Many hormones affect long-term changes like growth rate, **puberty** and pregnancy. Nerve impulses often cause a response in a very limited area of the body, like an eye-blink or a finger movement. Hormones often affect many organ systems at once.

Serious deficiencies or excesses of hormone production can cause illnesses. Small differences in hormone activity between individuals probably contribute to differences of personality and mood.

The position of the endocrine glands in the body is shown in Figure 14.19. Notice that the pancreas and the reproductive organs have a dual function.



▲ **Figure 14.19** Position of endocrine glands in the body

Adrenal glands

Adrenal glands are attached to the back of the abdominal cavity, one above each kidney (see also Figure 13.1), and produce the hormone adrenaline.

Adrenaline has obvious effects on the body, including the liver and the heart:

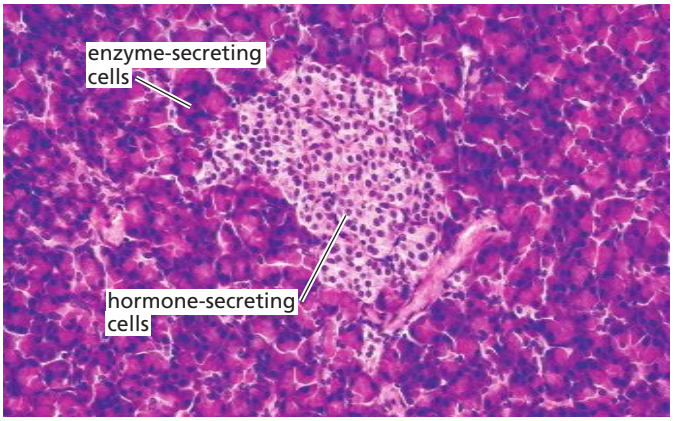
- In response to a stressful situation, nerve impulses are sent from the brain to the adrenal gland, which releases adrenaline into the blood.
- Its presence causes breathing to become faster and deeper. This may be particularly clear as we pant for breath.
- The heart beats faster, resulting in an increase in pulse rate. This increase in heart rate can be quite worrying, making us feel as if our heart is going to burst out of our chest.
- The pupils of our eyes dilate, making them look much blacker.
- In the liver it stimulates the conversion of glycogen to glucose. The glucose passes into the bloodstream. Its increased concentration increases the heart rate.
- Adrenaline has an important role in the control of metabolic activity. Increased levels of glucose available to cells enable them to respire faster, making more energy available.

These effects all make us more able to react quickly and strongly in dangerous situations (known as 'fight or flight' situations) when we might need to run away or put up a struggle. However, in many stressful situations, like taking examinations or giving a public performance, vigorous activity is not needed. So, the extra adrenaline in our bodies just makes us feel tense and anxious.

When adrenaline is no longer needed, it is quickly converted by the liver to a less active compound, which is excreted by the kidneys.

The pancreas

The pancreas is a digestive gland that secretes enzymes into the duodenum through the pancreatic duct (Chapter 8). It is also an endocrine (ductless) gland. Most of the pancreas cells produce digestive enzymes, but some of them produce hormones. The hormone-producing cells are arranged in small isolated groups called islets (Figure 14.20). They secrete their hormones directly into the bloodstream. One of the hormones is called insulin. Insulin controls the levels of glucose in the blood by instructing the liver to remove the sugars and store them. This happens when levels get too high, for example, after a meal rich in carbohydrate.



▲ **Figure 14.20** Section of pancreas tissue showing an islet (×250)

The pancreas also produces another hormone called **glucagon**. Glucagon is responsible for changing glycogen to glucose when blood glucose levels fall below normal (see the section on homeostasis later in this chapter). Be careful not to confuse glucagon with the carbohydrate glycogen!

Pituitary gland

This gland is attached to the base of the brain. It produces many hormones. For example, the pituitary releases into the blood **follicle-stimulating hormone (FSH)** which, when it reaches the **ovaries**, makes one of the follicles start to mature and produce **oestrogen**. **Luteinising hormone (LH)**, also known as lutropin, is also produced from the pituitary and, together with FSH, stimulates ovulation (see 'The menstrual cycle' in Chapter 16).

Reproductive organs

The ovaries and testes produce hormones as well as gametes (sperms and **egg cells**), and their effects are described in Chapter 16.

One of the hormones from the ovary, oestrogen, prepares the uterus for the implantation of the **embryo** by making its lining thicker and increasing its blood supply. After ovulation, the ovary produces **progesterone**. While progesterone levels remain high, the lining of the uterus is maintained.

The hormones **testosterone** (from the **testes**) and oestrogen (from the ovaries) play a part in the development of the **secondary sexual characteristics**.

Going further

Performance-enhancing hormones

In the last 30 years or so, some athletes and sports persons have made use of drugs to boost their performance. Some of these drugs are synthetic forms of hormones.

Testosterone is made in the testes of males and is responsible for promoting male primary and secondary sexual characteristics. Taking testosterone supplements (known as 'doping') leads to increased muscle and bone mass. The practice therefore has the potential to enhance a sportsperson's performance.

Some steroids are synthetic derivatives of testosterone. They affect protein metabolism, increasing muscle development and reducing body fat. As a result, athletic performance is improved. There are serious long-term effects of taking these steroids. One of the main effects are sterility, masculinisation in women, and liver and kidney malfunction.

The American Lance Armstrong (Figure 14.21) was a cyclist who won the Tour de France seven times and is a cancer survivor. In 2013, he admitted to doping throughout his career with testosterone, cortisone, EPO and blood transfusions. He has been stripped of all his titles.

▲ **Figure 14.21** Lance Armstrong

Because these drugs improve performance beyond what could be achieved by normal training, they are judged unfair and banned by most sports organisations. Performance-enhancing steroids are universally banned, as are other performance-enhancing drugs.

The products of the steroid hormones can be detected in the urine and this is the basis of most tests for banned substances. Without these regulations, sport would become a competition between synthetic chemical substances rather than between individuals and teams.

Test yourself

10 a Name the organ systems which involve
- **i)** hormones
- **ii)** nerve impulses.

b State three differences between these two systems.

11 Use straight lines to match each of the hormones with their glands and function.

hormone	gland	function
adrenaline	pancreas	development of testes
insulin	ovaries	increases heart rate
oestrogen	testes	controls levels of glucose in the blood
testosterone	adrenal	prepares the uterus for implantation of an embryo

12 Sometimes the victims of car crashes suffer damage to the pancreas, which results in removal of the organ. Suggest, with reasons, what problems the patient might have without a pancreas.

Homeostasis

FOCUS POINTS

- ★ What is homeostasis?
- ★ What is negative feedback?
- ★ How does the body control glucose concentration in the blood?
- ★ How is Type 1 diabetes treated?
- ★ What are the components of skin?
- ★ How do mammals control their internal body temperature?

Key definitions

Homeostasis is the maintenance of a constant internal environment.

Set point is the physiological value around which the normal range fluctuates.

Homeostasis literally means *staying similar*. One example of this is the way the endocrine system maintains levels of glucose in the blood. After a meal containing carbohydrates, the product of digestion is glucose. This is absorbed into the bloodstream, making the levels higher than normal. In response, the pancreas secretes insulin, which travels in the blood to the liver. Insulin stimulates the liver to remove glucose from the blood, bringing the level back to normal.

Homeostasis refers to the fact that the composition of the tissue fluid (see 'Blood' in Chapter 11) in the body is kept within narrow limits. The concentration, acidity and temperature of fluid are being adjusted all the time to prevent any big changes. There is a set point, which is a value around which the normal range fluctuates. For example, the set point for human body temperature is about 37 °C. Any significant divergence from this triggers a mechanism to bring the temperature back to its set point.

In Chapter 5 it was explained that, in living cells, all the chemical reactions are controlled by enzymes. The enzymes are very sensitive to the conditions in which they work. A slight fall in temperature or a rise in acidity may slow down or stop an enzyme from working. This would prevent an important reaction from taking place in the cell.

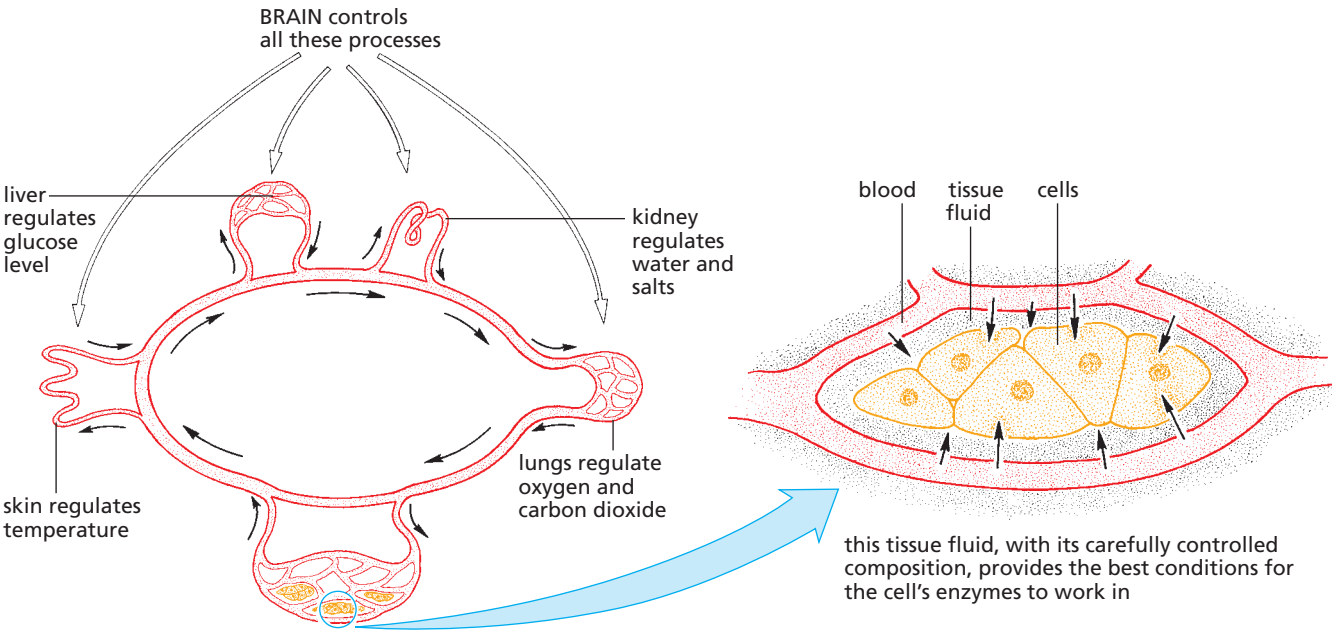
The cell membrane controls the substances that enter and leave the cell, but the tissue fluid supplies or removes these substances. So, it is important to keep the composition of the tissue fluid as steady as possible. If the tissue fluid became too concentrated, it would withdraw water from the cells by osmosis (Chapter 3) and the body would be dehydrated. If the tissue fluid became too dilute, the cells would take up too much water from it by osmosis and the tissues would become swollen. The cells may even burst.

Many systems in the body help with homeostasis (Figure 14.22). The obvious example is the kidneys, which remove substances that might poison the enzymes. The kidneys also control the level of salts, water and acids in the blood. The composition of the blood affects the tissue fluid which, in turn, affects the cells.

Another example of a homeostatic organ is the liver, which regulates the level of glucose in the blood. The liver stores any excess glucose as glycogen, or turns glycogen back into glucose if the concentration in the blood gets too low. The brain cells are very sensitive to the glucose concentration in the blood. If the level drops too far, they stop working properly and the person becomes unconscious, and will die unless glucose is injected into the blood system. This shows how important homeostasis is to the body.

Temperature regulation is another example of homeostasis. Maintenance of a constant body temperature makes sure that vital chemical reactions continue at a predictable rate and do not speed up or slow down when the surrounding temperature changes. So, the constant-temperature (warm-blooded) animals, the birds and mammals, have an advantage over the variable-temperature (cold-blooded) animals. Animals like reptiles and insects can control their body temperature to some extent by, for example, basking in the sun or finding shade. However, if their body temperature falls, their vital chemistry slows down and their reactions become slower. This makes them more at risk of being caught by predators.

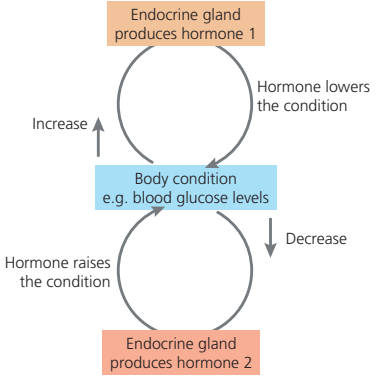
The cost to warm-blooded animals is the intake of enough food to maintain their body temperature, usually above that of their surroundings.



▲ **Figure 14.22** The homeostatic mechanisms of the body

Homeostasis and negative feedback

Homeostasis works through a system of control called negative feedback (Figure 14.23). The outgoing impulses counteract the effects produced by the incoming impulses. For example, a rise in blood glucose levels triggers responses that counteract the rise (e.g. through the release of insulin).



▲ **Figure 14.23** How negative feedback works

In the brain of a warm-blooded animal there is a thermoregulatory centre. This centre monitors the temperature of the blood passing through it. It also receives sensory nerve impulses from temperature receptors in the skin. A rise in body temperature is detected by the thermoregulatory centre and it sends nerve impulses to the skin, which result in vasodilation and sweating. In the same way, a fall in body temperature will be detected and will trigger impulses that produce **vasoconstriction** and shivering.

The brain has overall control of the homeostatic processes in the body. It checks the composition of the blood flowing through it. If it is too warm, too cold, has too much or too little glucose, nerve impulses or hormones are sent to the organs concerned, causing them to make the necessary adjustments.

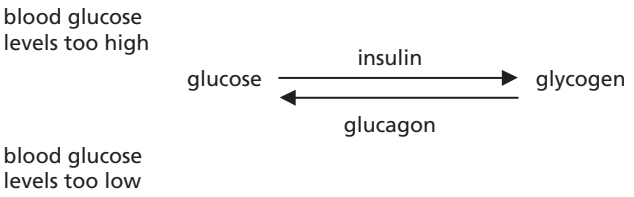
Controlling the levels of blood glucose

If the level of sugar in the blood falls, the islets in the pancreas release a hormone called glucagon into the bloodstream. Glucagon acts on the cells in the liver and causes them to convert some of their stored glycogen into glucose. This restores the blood sugar level.

Insulin has the opposite effect to glucagon. If the concentration of blood sugar increases (e.g. after a meal rich in carbohydrate), insulin is released from the islet cells of the pancreas. When the insulin reaches the liver, it stimulates the liver cells to take up glucose from the blood and store it as glycogen.

Insulin has many other effects; it increases the uptake of glucose in all cells for use in respiration; it increases the conversion of carbohydrates to fats and slows down the conversion of protein to carbohydrate.

All these changes have the effect of regulating the level of glucose in the blood to within narrow limits – a very important example of homeostasis.



The concentration of glucose in the blood of a person who has not eaten for 8 hours is usually between 90 and 100 mg 100 cm^{-3} blood. After a meal containing carbohydrate, the blood sugar level may rise to 140 mg 100 cm^{-3}. However, 2 hours later, the level returns to about 95 mg because the liver has converted the excess glucose to glycogen.

About 100 g glycogen is stored in the liver of a healthy man. If the concentration of glucose in the blood falls below about 80 mg 100 cm^{-3} blood, some of the glycogen stored in the liver is converted by enzyme action into glucose, which enters the circulation. If the blood sugar level rises above 160 mg 100 cm^{-3}, glucose is excreted by the kidneys.

A blood glucose level below 40 mg 100 cm^{-3} affects the brain cells badly, leading to convulsions and coma. By helping to keep the glucose concentration between 80 and 150 mg, the liver prevents these undesirable effects. In this way, it supports the homeostasis of the body.

If blood glucose levels remain too high for long periods, serious health problems can develop. The condition is called hyperglycaemia. Effects include damage to vessels that supply blood to vital organs, which can increase the risk of heart disease and stroke, kidney disease, blurred vision and nerve problems.

If anything goes wrong with the production or function of insulin, the person will show the symptoms of **diabetes**.

Type 1 diabetes

There are two types of diabetes and Type 1 is the less common form. It happens when the islet cells of the pancreas do not produce enough insulin. As a result the patient's blood is low in insulin and he or she needs regular injections of the hormone in order to control blood sugar level and so lead a normal life. This form of the disease is sometimes called *insulin-dependent diabetes*. The patient is unable to control the level of glucose in the blood. It may rise to such a high level that it is excreted in the urine, or fall so low that the brain cells cannot work properly and the person goes into a coma.

The signs of diabetes include increased blood glucose concentration and the presence of glucose in urine. The symptoms include feeling tired, feeling very thirsty, frequent urination and weight loss. The weight loss is because the body starts to break down muscle and fat.

Diabetics with Type 1 diabetes need a carefully controlled diet, to keep the blood sugar within reasonable limits, and must take regular exercise. They need to have regular blood tests to monitor their blood sugar levels, with regular injections of insulin to control them.

Skin structure

Figure 14.24 shows a section through skin. In the *basal layer* some of the cells are constantly dividing and pushing the older cells nearer the surface. Here they die and are shed at the same rate as they are replaced. The basal layer and the cells above it make up the epidermis. The basal layer also produces the hair follicles. The dividing cells form the hair. **Hair erector muscles** are attached to each of the hairs. When they contract, the hairs become erect.

The thickness of the epidermis and the quantity of hairs vary in different parts of the body (Figure 14.25).

The *dermis* contains connective tissue with hair follicles, sebaceous glands, **sweat glands**, blood vessels and nerve endings. There is usually a layer of fatty tissue (a fat deposit) beneath the dermis.

The skin and temperature control

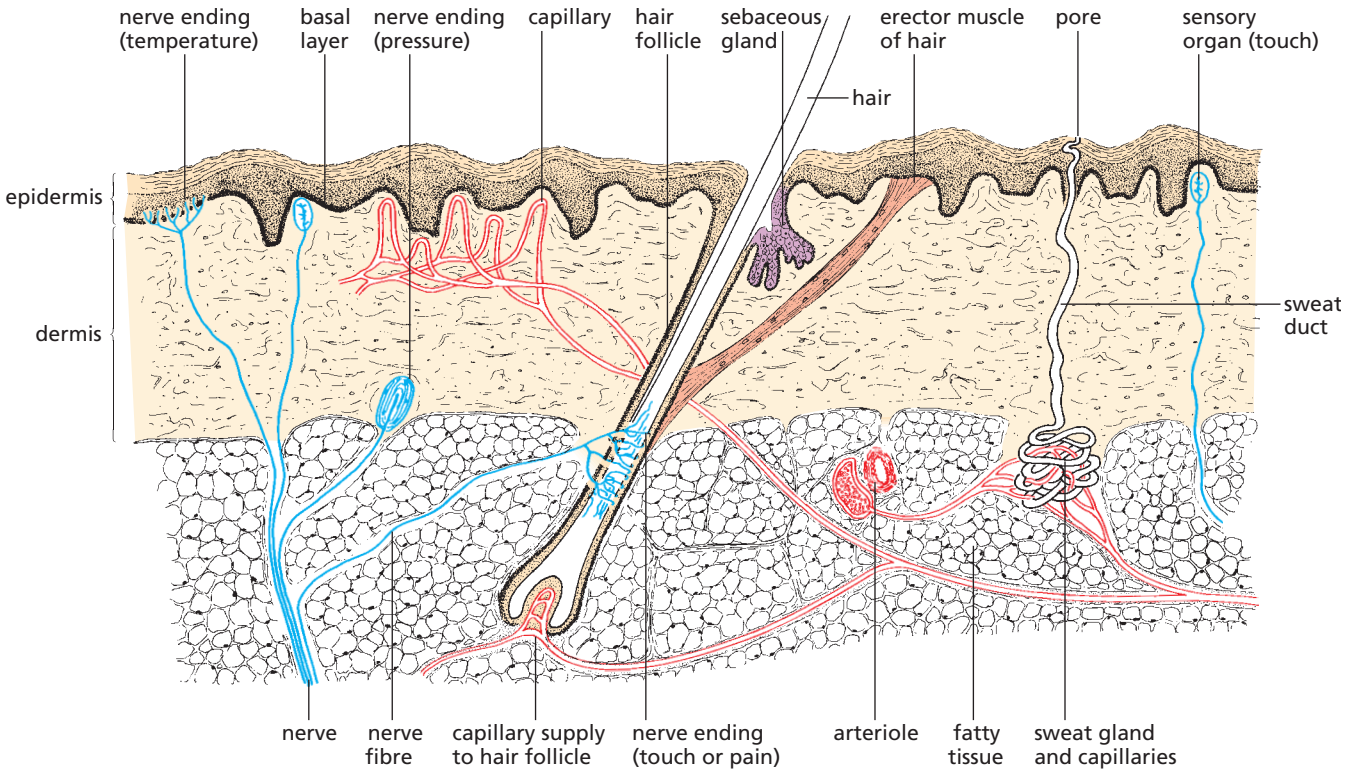
The skin helps to keep the body temperature steady. This is done by adjusting the flow of blood near the skin surface and by sweating. These processes are described more fully below.

Normal human body temperature varies between 35.8 °C and 37.7 °C. If maintained for long, temperatures below 34 °C or above 40 °C can be dangerous. Different body regions, for example, the hands, feet, head or internal organs, will be at different temperatures, but the *core* temperature, as measured with a thermometer under the tongue, will only vary by 1 or 2 °C.

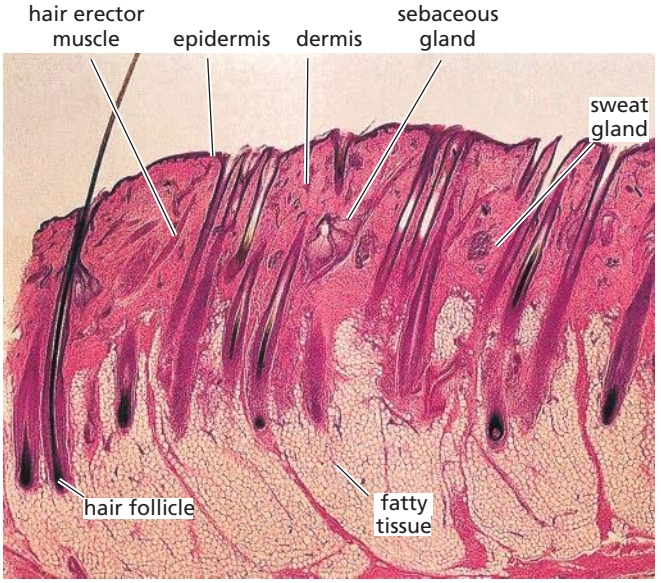
Heat is lost from the body surface by conduction, convection, radiation and evaporation. The **insulating** properties of fatty tissue in the dermis help to reduce the amount of heat lost. Some mammals living in extreme conditions, like whales and seals, make much greater use of this: they have

thick layers of blubber to reduce heat loss more effectively. How much insulation the blubber gives depends on the amount of water in the tissue: a smaller proportion of water and more fat give better insulating properties.

Internally, heat is gained from the process of respiration (Chapter 10) in the tissues and, externally, from the surroundings or from the Sun.



▲ **Figure 14.24** Generalised section through the skin



▲ **Figure 14.25** Section through hairy skin (×20)

The two processes of heat gain and heat loss normally balance each other, but any imbalance is corrected by a number of methods, including those described below.

Overheating

- More blood flows near the surface of the skin, allowing more heat to be exchanged with the surroundings.
- Sweating – the sweat glands secrete sweat on to the skin surface. When this layer of liquid evaporates, it takes heat from the body and cools it down (Figure 14.26).

▲ **Figure 14.26** Sweating. During vigorous activity the sweat evaporates from the skin and helps to cool the body. When the activity stops, continued evaporation of sweat may overcool the body unless it is removed with a towel

Overcooling

- Less blood flows near the surface of the skin, reducing the amount of heat lost to the surroundings.
- Sweat production stops, so the heat lost by evaporation is reduced.
- **Shivering** – uncontrollable bursts of rapid muscular contraction in the limbs release heat as a result of respiration in the muscles.
- Hair erector muscles contract, pulling the hairs so that they stand upright. In doing so, they trap air against the surface of the skin, which helps to insulate it against further heat loss.

Vasodilation and vasoconstriction

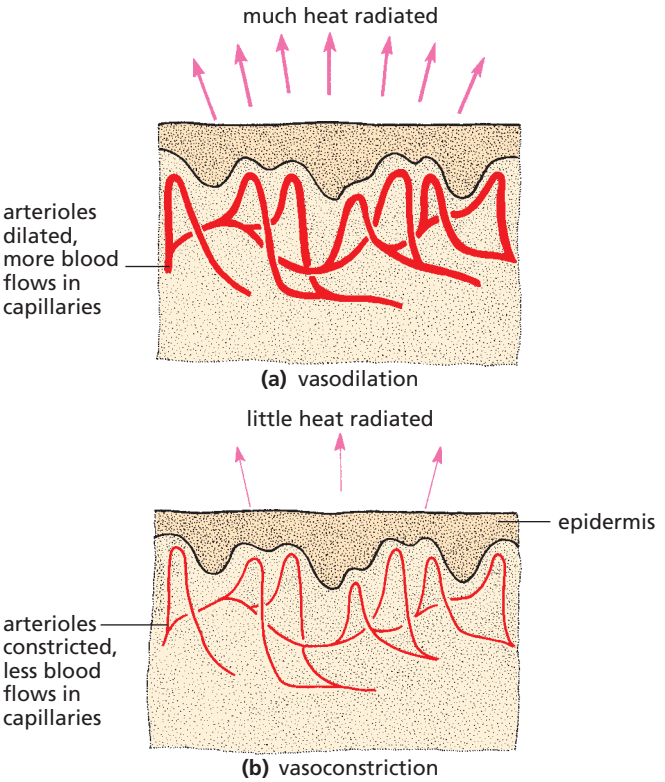
In addition to the methods already described, the skin has another very important mechanism for maintaining a constant body temperature. This involves arterioles in the dermis of the skin, which can widen or narrow to allow more or less blood to flow near the skin surface through the blood capillaries.

Vasodilation – the widening of the arterioles in the dermis allows more warm blood to flow through blood capillaries near the skin surface, resulting in heat loss (Figure 14.27(a)).

Vasoconstriction – narrowing (constriction) of the arterioles in the skin reduces the amount of warm blood flowing through blood capillaries near the surface (Figure 14.27(b)).

In these ways, the body temperature remains at about 37 °C. We also control our temperature by adding or removing clothing or deliberately taking exercise.

Whether we feel hot or cold depends on the sensory nerve endings in the skin, which respond to heat loss or gain. You cannot consciously detect changes in your core temperature. The brain plays a direct role in detecting any changes from normal by monitoring the temperature of the blood. A region in the brain called the **hypothalamus** contains a thermoregulatory centre in which temperature receptors detect temperature changes in the blood and co-ordinate a response to them. Temperature receptors are also present in the skin. They send information to the brain about temperature changes.



▲ **Figure 14.27** Vasodilation and vasoconstriction

Test yourself

13 a Define the term *homeostasis*.
b Describe the role of insulin in homeostasis.
14 What conscious actions do we take to reduce the heat lost from the body?
15 a What sort of chemical reaction in active muscle will produce heat?
b How does this heat get to other parts of the body?
16 a State which structures in the skin of a furry mammal help to reduce heat loss.
b Describe the changes that take place in the skin of humans to reduce heat loss.
17 Sweating cools you down only if the sweat can evaporate.
Suggest in what conditions
a the sweat would be unable to evaporate from your skin
b the evaporation of sweat could speed up and so make you feel very cold.

Revision checklist

After studying Chapter 14 you should know and understand the following:

- ✔ Electrical impulses travel along neurones.
- ✔ The central nervous system consists of the brain and the spinal cord.
- ✔ The peripheral nervous system consists of the nerves.
- ✔ The nervous system coordinates and regulates body functions.
- ✔ There are three types of neurone, each with distinct features.
- ✔ A reflex is a rapid, automatic nervous reaction that cannot be consciously controlled.
- ✔ A reflex arc is the nervous pathway that carries the impulses causing a reflex.
- ✔ Reflexes have a protective function.
- ✔ A synapse is a junction between two neurones consisting of a minute gap across which impulses pass by diffusion of a neurotransmitter.
- ✔ Identify parts of a synapse and describe how it transmits an impulse from one neurone to another.
- ✔ In reflex arcs, synapses ensure the movement of impulses in one direction.
- ✔ Sense organs are groups of receptor cells responding to specific stimuli: light, sound, touch, temperature and chemicals.
- ✔ Describe the structure of the eye.
- ✔ Describe the function of the parts of the eye.
- ✔ Explain the pupil reflex in terms of the antagonistic action of muscles in the iris.
- ✔ Explain accommodation to view near and distant objects.
- ✔ Describe the roles of parts of the eye in accommodation.
- ✔ State the distribution of rods and cones in the retina of a human.
- ✔ Describe the function of rods and cones.
- ✔ The position of the fovea and its function.
- ✔ A hormone is a chemical substance, produced by a gland and carried by the blood, which alters the activity of one or more specific target organs.
- ✔ The testes, ovaries, and pancreas and adrenal glands are endocrine glands.
- ✔ The endocrine glands release hormones into the blood system.
- ✔ When the hormones reach certain organs, they change the rate or kind of activity of the organ.
- ✔ Adrenaline is secreted in 'fight or flight' situations.
- ✔ It causes an increased breathing and pulse rate and widened pupils.
- ✔ Adrenaline has a role in the chemical control of metabolic activity, including increasing the blood glucose concentration and pulse rate.
- ✔ The nervous system is much faster, and its action tends to be over a shorter time span than hormonal control systems.
- ✔ Homeostasis is the maintenance of a constant internal environment.
- ✔ Insulin decreases blood glucose concentration.
- ✔ Negative feedback provides a means of control: if levels of substances in the body change, the change is monitored and a response to adjust levels to a set point is brought about.
- ✔ Glucose concentration in the blood is controlled using insulin and glucagon.
- ✔ Type 1 diabetes is the result of islet cells in the pancreas failing to produce enough insulin.

- ✔ The signs of diabetes include increased blood glucose concentration and the presence of glucose in urine.
- ✔ Type 1 diabetes is treated with insulin.
- ✔ The structure of the skin.
- ✔ Skin controls the body temperature.
- ✔ If the body temperature rises too much, the skin cools it down by sweating and vasodilation.
- ✔ If the body loses too much heat, vasoconstriction and shivering help to keep it warm.
- ✔ The brain monitors the temperature of the blood.

Exam-style questions

1 a Define the term *synapse*. [2]

b By what process do neurotransmitter molecules travel across the synapse? [1]

c The width of a synaptic cleft is 2.0×10^{-2} μm.
The time taken for neurotransmitter molecules to diffuse across the gap is 4.0×10^{-10} seconds.
Calculate the speed of transmission across the synapse, in m s^{-1}. [3]

2 Modify the diagram in Figure 14.23 to show the role of negative feedback in the maintenance of blood glucose levels. [4]

3 a Describe how sensory neurones and motor neurones are similar

i) in structure [4]

ii) in function. [1]

b State how they are different. [4]

4 a Define the term *reflex action*. [3]

b i) Complete the flow chart by putting the terms coordinator, effector, receptor, response and stimulus in the correct order to show the stages in a reflex arc. [2]

ii) On the flow chart label where you would find the

1 relay neurone

2 motor neurone

3 sensory neurone. [3]

c Describe the events that occur from the moment a person stands on a sharp pin to when she lifts her foot away. [9]

5 a Describe the structure of a synapse. [4]

b State how neurotransmitter molecules move across the gap. [1]

c State one advantage and one disadvantage of having synapses between neurones. [2]

6 a Construct a table listing five parts of the eye and their functions. [5]

b Explain how exposure of the eye to a sudden bright light brings about a response in the iris. [8]

7 Suggest how damage to three named parts of the eye could lead to impaired vision or blindness. [3]

8 A student carried out an experiment to study the eye's response to light. A lamp was shone into his eyes then moved to various distances away from him. The diameter of the student's pupil was measured each time the lamp was moved. The table shows the results.

position of lamp	diameter of pupil/mm
1	3.2
2	4.1
3	4.7
4	4.9
5	3.7
6	2.6
7	1.8

a State in which position the lamp was nearest the eye. [1]

b Describe what was happening to the brightness of the lamp between positions 1 and 4. [1]

c Describe and explain the changes to the iris when the eye responded to changes in light intensity between positions 5 and 7. [4]

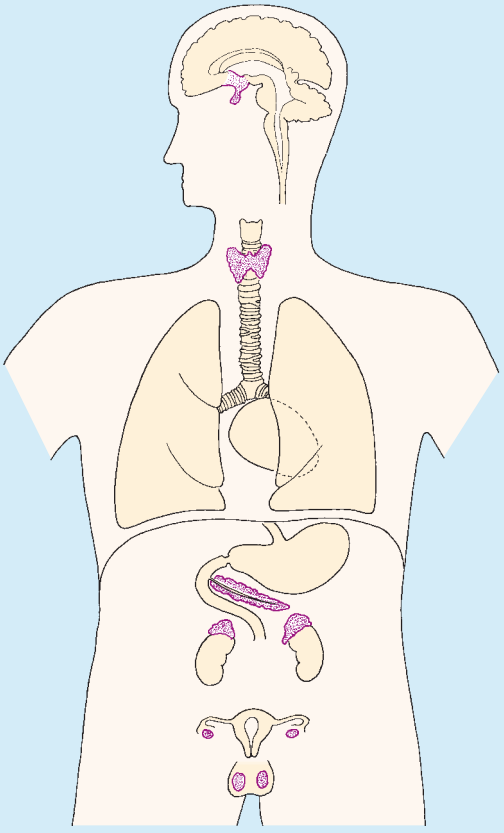
d i) Name the type of response being shown by the eye. [1]

ii) State how this response benefits the eye. [1]

9 a i) Define the term *hormone*. [3]

ii) Describe the structure of the endocrine system. [2]

b The diagram of the human body shows some parts of the endocrine system.



On the diagram, label the glands listed below and state what hormone each gland produces:

i) pancreas

ii) adrenal gland

iii) ovary

iv) testis

v) pituitary gland. [10]

10 An athlete is about to run a race and her adrenaline level rises.

a Describe and explain the effect of this increase in adrenaline on the athlete's body. [4]

b The athlete gets hotter during the race. Describe how the body responds to return her body temperature to normal. [6]

11 a Define the term *homeostasis*. [2]

b Suggest in what situations a healthy person's blood glucose level might be expected to:

i) rise

ii) fall. [4]

c Describe how the blood glucose level is maintained. [8]

15 Coordination and response in plants

Focus

In the previous chapter we explored how coordination and control is achieved in mammals by means of nervous and endocrine systems. Plants have ways of coordinating their growth so that they benefit from where the most light or water is. This chapter will explore how plants respond to stimuli.

Tropic responses

FOCUS POINTS

- ★ What is gravitropism?
- ★ What is phototropism?
- ★ How do gravitropism and phototropism control plant growth?
- ★ How does auxin control plant growth?
- ★ How can you investigate the effects of gravitropism and phototropism on plant shoots and roots?

Sensitivity is the ability of living organisms to respond to stimuli. Although plants do not respond by moving their whole bodies, parts of them do respond to stimuli. Some of these responses are described as tropic responses or tropisms.

Tropisms

Key definitions

Gravitropism is a response in which parts of a plant grow towards or away from gravity.

Phototropism is a response in which parts of a plant grow towards or away from light.

Tropisms are growth movements related to directional stimuli, for example, a shoot will grow towards a source of light but away from the direction of gravity. Growth movements of this kind are usually in response to the *direction* of light or gravity. Responses to light are called phototropisms; responses to gravity are gravitropisms.

If the plant organ responds by growing towards the stimulus, the response is said to be 'positive'. If the response is growth away from the stimulus it is said to be 'negative'. For example, if a plant is placed horizontally, its stem will change its direction and grow upwards, away from gravity (Figure 15.1).

▲ **Figure 15.1** Negative gravitropism. The tomato plant has been left on its side for 24 hours

The shoot is negatively gravitropic. The roots, however, will change their direction of growth to grow vertically downwards towards the pull of gravity (experiment 1, Gravitropism in pea radicles). So, roots are positively gravitropic.

Phototropism and gravitropism are shown best in simple controlled experiments. Seedlings are good material for experiments on sensitivity because their growing roots (radicles) and shoots respond quickly to the stimuli of light and gravity.

Practical work

Safety

- Eye protection must be worn.

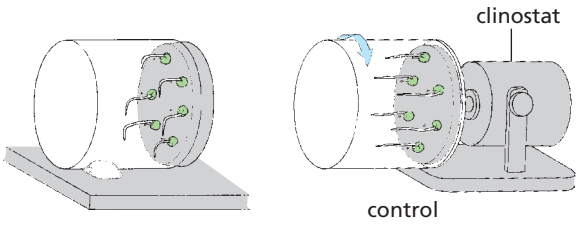
Experiments on tropisms

1 Gravitropism in pea radicles

- Ideally this experiment uses a piece of apparatus called a clinostat. A clinostat is a clockwork or electric turntable, which can be set to rotate slowly about four times an hour.
- Soak about 20 peas in water for a day and then let them germinate in a vertical roll of moist blotting paper.
- After 3 days, choose 12 seedlings with straight radicles and pin six of these to the turntable of a clinostat so that the radicles are horizontal. Although gravity is pulling sideways on their roots, it will pull equally on all sides as they rotate.
- Pin another six seedlings to a cork that will fit in a wide-mouthed jar. Leave the jar on its side.
- Place the jar and the clinostat in the same conditions of lighting or leave them in darkness for 2 days.

Result

The radicles in the clinostat will continue to grow horizontally, but those in the jar will have changed their direction of growth to grow vertically downwards (Figure 15.2).



▲ **Figure 15.2** Results of an experiment to show gravitropism in roots

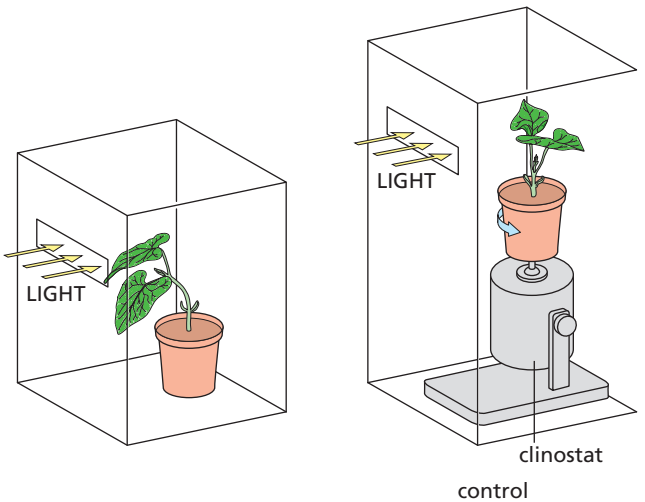
Interpretation

The stationary radicles have responded to the stimulus of one-sided gravity by growing towards it. The radicles are positively gravitropic.

The radicles in the clinostat are the controls. Rotation of the clinostat has allowed gravity to act on all sides equally and there is no one-sided stimulus, even though the radicles were horizontal.

2 Phototropism in shoots

- Select two potted seedlings (e.g. sunflower or runner bean) of similar size and water them both.
- Place one of them under a cardboard box with a window cut in one side so that light reaches the shoot from only one direction (Figure 15.3).
- Place the other plant in an identical situation but on a clinostat. This will rotate the plant about four times per hour and expose each side of the shoot equally to the source of light. This is the control.



▲ **Figure 15.3** Experiment to show phototropism in a shoot

Result

After 1 or 2 days, the two plants are removed from the boxes and compared. It will be found that the stem of the plant with one-sided illumination has changed its direction of growth and is growing towards the light (Figure 15.4). The control shoot has continued to grow vertically.

▲ **Figure 15.4** Positive phototropism. The plant has received one-sided lighting

Interpretation

The results suggest that the young shoot has responded to one-sided lighting by growing towards the light. The shoot is said to be positively phototropic because it grows towards the direction of the stimulus.

However, the results of an experiment with a single plant cannot be used to draw conclusions that apply to all green plants. The experiment described here is more of an illustration than a critical investigation. To investigate phototropisms thoroughly, many plants from a wide variety of species would have to be used.

Practical work questions

1 For experiment 1, explain why a clinostat is useful in this experiment.
2 For experiment 2, suggest what would happen if a pot of seedlings was placed in a light-proof box with no window for two days.

Advantages of tropic responses

Positive phototropism of shoots

By growing towards the source of light, a shoot brings its leaves into the best situation for photosynthesis. Similarly, the flowers are brought into an exposed position where they are most likely to be seen and pollinated by flying insects.

Negative gravitropism in shoots

Shoots that are negatively gravitropic grow vertically. This lifts the leaves and flowers above the ground and helps the plant to compete for light and carbon dioxide. The flowers are brought into a beneficial position for insect or wind pollination. Seed dispersal may be more effective from fruits on a long, vertical stem. However, these advantages are a product of a tall shoot rather than negative gravitropism.

Stems that form rhizomes (stems that grow underground) are not negatively gravitropic; they grow horizontally below the ground, though the shoots that grow up from them are negatively gravitropic.

Positive gravitropism in roots

By growing towards gravity, roots move deeper into the soil, which is their means of anchorage and their source of water and mineral ions.

Plant growth substances and tropisms

Control of growth

In animals and plants, the growth rate and amount of growth are controlled by chemicals: hormones in animals and growth substances in plants.

One of the growth substances is **auxin**. It is produced in the tips of actively growing roots

and shoots and moves by diffusion (Chapter 3) to the regions of extension where it stimulates cell enlargement (Figure 15.5).

The responses made by shoots and roots to light and gravity are influenced by growth substances.

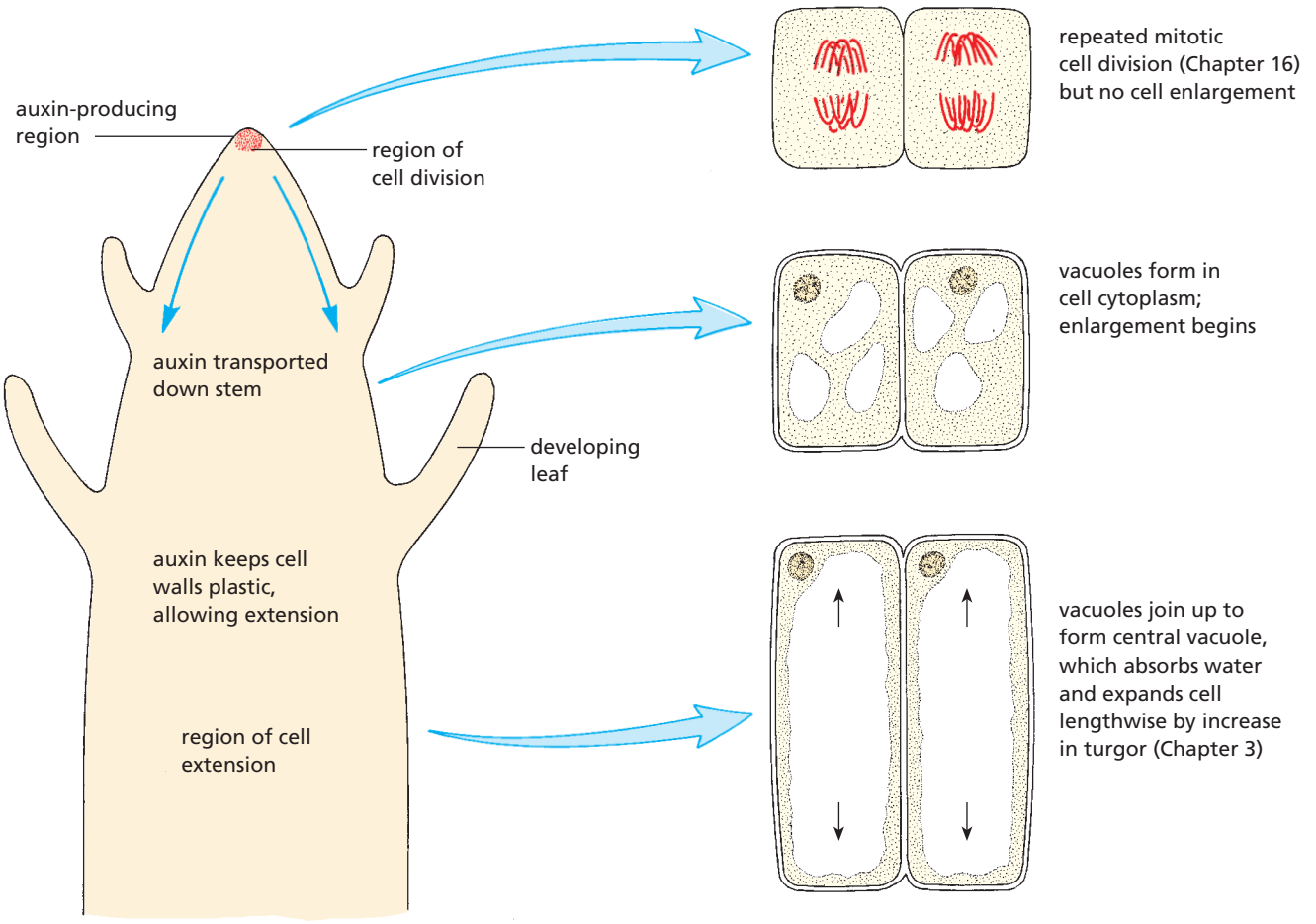
It has already been explained that growth substances (e.g. auxin) are produced by the tips of roots and shoots and can stimulate or, in some cases, prevent extension growth. Tropic responses could be explained if the one-sided stimuli produced a one-sided distribution of growth substance in response.

Summary of control of shoot growth by auxin

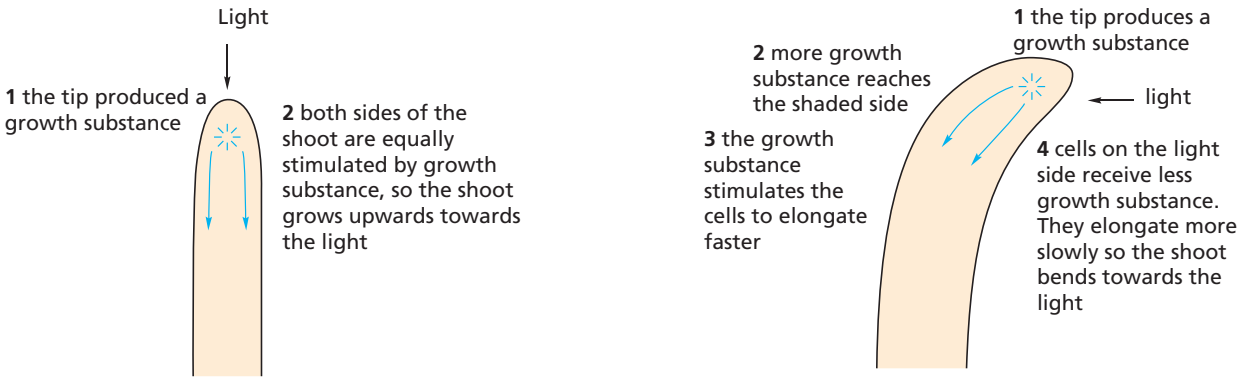
In the case of phototropism, scientists accept that the distribution of growth substance causes reduced extension on the illuminated side and/or increased extension on the non-illuminated side.

When a shoot is exposed to light from one side, auxins that have been produced by the tip move towards the shaded side of the shoot (or the auxins are destroyed on the light side), causing an unequal distribution. Cells on the shaded side are stimulated to elongate more than those on the light side. The unequal growth causes the stem to elongate and bend towards the light. Growth of a shoot towards light is called positive phototropism.

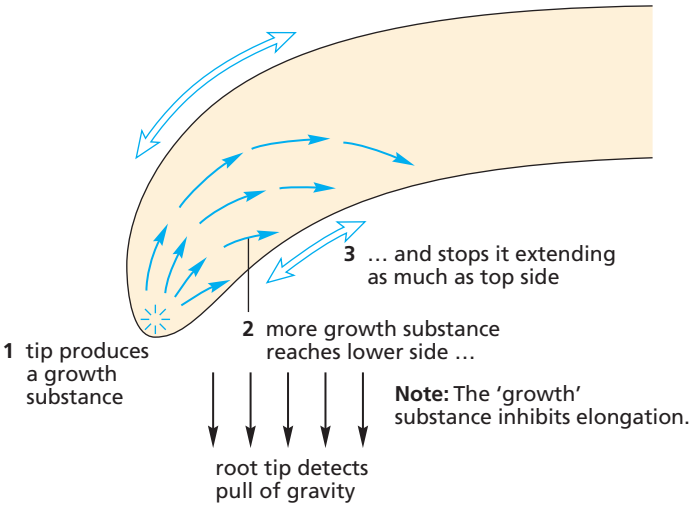
If a shoot is placed horizontally in the absence of light, auxins build up on the lower side of the shoot, due to gravity. This makes the cells on the lower side elongate *faster* than those on the upper side, so the shoot bends upwards. This is called negative gravitropism.



▲ **Figure 15.5** Extension growth at a shoot tip



▲ **Figure 15.6** Possible explanation of positive phototropism in shoots

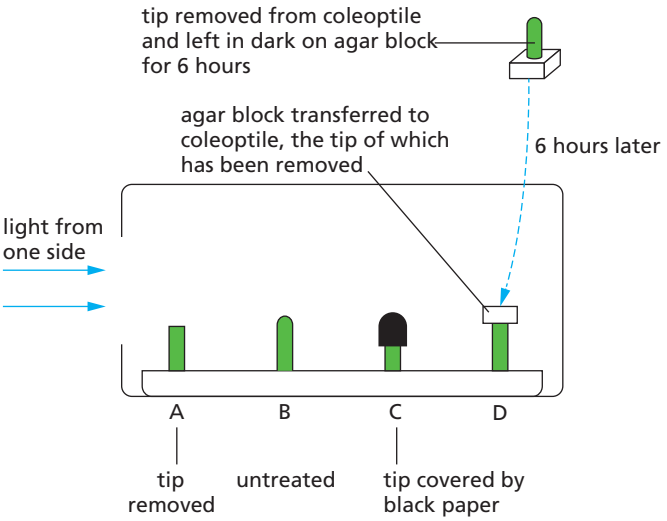


▲ **Figure 15.7** Possible explanation of positive gravitropism in roots

The opposite applies to roots because root cell elongation appears to be slowed down by exposure to auxin.

Classic experiments to test how auxins work

Wheat and other grass species belong to the monocotyledon group of flowering plants (Chapter 2). When wheat seeds germinate (start to grow) they produce a shoot covered by a protective sheath called a *coleoptile*. This helps to prevent damage to the new leaves as they push through the soil. The coleoptile shows responses to light and gravity in a similar way to other plant parts. Wheat coleoptiles only take 2 or 3 days to grow and they show responses very quickly, so they are ideal for tropism experiments. The tip of the coleoptile, where it is expected that auxins would be produced, can be cut off without killing the plant, effectively removing the source of the auxin.



▲ **Figure 15.8** Investigation into how auxin works

Figure 15.8 shows an investigation, treating coleoptiles in different ways.

Results

A No elongation of the coleoptile occurs and there is no bending.
B The coleoptile grows taller and bends towards the light.
C The coleoptile grows taller, but there is no bending.
D The coleoptile grows taller and bends towards the light.

Interpretation

In **A**, the source of auxin has been removed. Auxin is needed to stimulate elongation and stimulates a response to light. It could also be argued that the tip provides cells for growth and this source of cells has been removed.

In **B**, auxin is produced by the tip of the coleoptile. It diffuses down the coleoptile and collects on the shaded side (or is destroyed by the light on the light side). Cells on the shaded side respond to the auxin by elongating faster than on the light side, causing the coleoptile to grow towards the light.

In **C**, auxin is produced by the tip and diffuses down, causing all cells on both sides of the coleoptile to elongate at an equal rate, and so causing an increase in length. However, the black paper prevents the light influencing the auxin, so there is no response to the direction of light.

In **D**, auxin is produced by the tip of the coleoptile. It diffuses into the agar block. When the agar block is replaced on the cut coleoptile, the auxin diffuses down from the agar and collects on the shaded side of the coleoptile (or is destroyed by the light on the light side). Cells on the shaded side respond to the auxin by elongating faster than on the light side, causing the coleoptile to grow towards the light.

Going further

Use of plant growth substances

Chemicals can be manufactured which are very similar natural growth substances and may be used to control various stages of growth and development of crop plants.

The weed killer, 2,4-D, is very similar to one of the auxins. When sprayed on a lawn, it affects the broad-leaved weeds (the dicotyledons – see Chapter 2) but not the grasses. (It is called a *selective weed killer*.) Among other effects, it deforms the weeds' growth and speeds up their rate of respiration so much that they use up all their food reserves and die.

Test yourself

1 In Figure 15.9 the two sets of bean seedlings were sown at the same time, but the pot on the right was kept under a light-proof box. From the evidence in the picture
   - **a** describe what effects the light appears to have on growing seedlings
   - **b** suggest how this might explain positive phototropism.

Figure 15.9 Effect of light on shoots

Revision checklist

After studying Chapter 15 you should know and understand the following:

- ✔ A response related to the direction of the stimulus is a tropism.
- ✔ The roots and shoots of plants may respond to the stimuli of light or gravity.
- ✔ Gravitropism is a response in which a plant grows towards or away from gravity.
- ✔ Phototropism is a response in which a plant grows towards or away from the direction from which light is coming.
- ✔ Describe investigations into gravitropism and phototropism in shoots and roots.
- ✔ Explain phototropism and gravitropism of a shoot as examples of the chemical control of plant growth by auxin.
- ✔ Auxin is unequally distributed in response to light and gravity.
- ✔ Auxin stimulates cell elongation.

Exam-style questions

1 a To what directional stimuli do
- **i)** roots respond
- **ii)** shoots respond? [2]

b Name the plant organs that
- **i)** grow towards light
- **ii)** grow towards gravity
- **iii)** grow away from gravity. [3]

2 a Explain how auxins in a plant shoot that is placed in one-sided light change the direction of its growth. [5]

b Suggest how the plant will benefit from the change in direction of shoot growth. [2]

16 Development of organisms and continuity of life

Focus

No organism can live for ever, but part of it lives on in its offspring. Offspring are produced by the process of reproduction. This process may be sexual or asexual, but in either case it results in the continuation of the species. In Chapter 1 you were introduced to structure and function of gametes (sperm and egg cells). You know that new cells are produced by the division of existing cells. In this chapter we will develop this principle to whole living organisms. How do plants and animals grow and develop? How do plants reproduce? Are there any similarities between these processes in plants and in animals?

Chromosomes, genes and nuclei

FOCUS POINTS

- ★ What are chromosomes made of?
- ★ What are genes?
- ★ What is a haploid nucleus?
- ★ What is a diploid nucleus?
- ★ How many of each type of chromosome are there in a diploid cell?
- ★ How many chromosomes are in a human diploid cell?

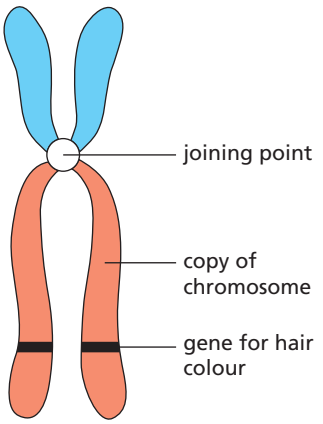
Key definitions

A **haploid nucleus** is a nucleus containing a single set of chromosomes.

A **diploid nucleus** is a nucleus containing two sets of chromosomes.

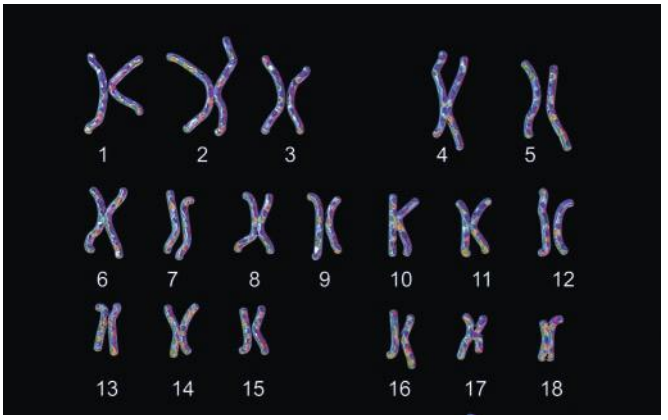
A chromosome contains a DNA molecule, which carries genetic information in the form of genes. A gene is a length of DNA that codes for a protein.

Inside a nucleus are thread-like structures called chromosomes, which can be seen most clearly when the cell is dividing. Each chromosome has specific characteristics when it is ready to divide: it makes a copy, joined at one point (Figure 16.1). Each is a string of genes coding for the person's characteristics. The copied chromosome carries the same genes in the same order.



▲ **Figure 16.1** Structure of a chromosome

A human body cell nucleus contains 46 chromosomes. These are difficult to distinguish when packed inside the nucleus, so scientists separate them and arrange them according to size and appearance (Figure 16.2). There are pairs of chromosomes. The only pair that do not necessarily match is chromosome pair 23, called the sex chromosomes. The Y chromosome is much smaller than the X chromosome.



▲ **Figure 16.2** Human chromosomes

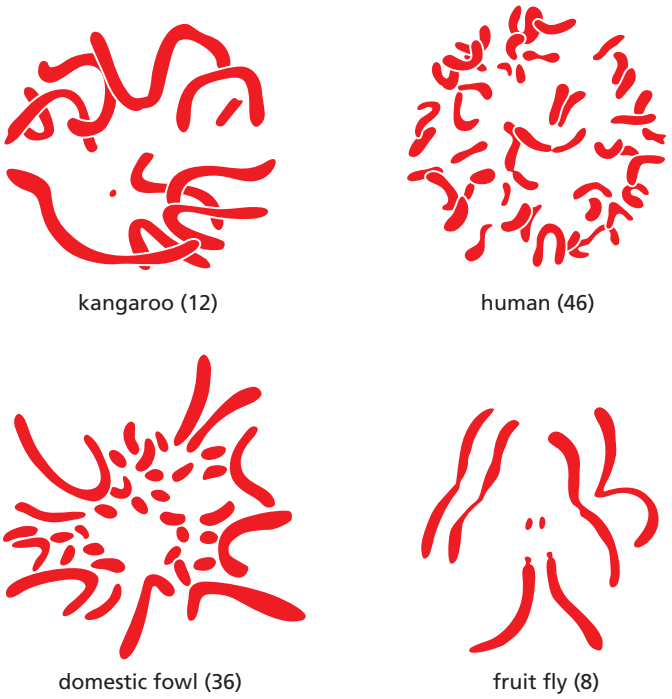
Number of chromosomes

There is a fixed number of chromosomes in each species. Human body cells each contain 46 chromosomes, mouse cells contain 40 and garden pea cells 14 (see also Figure 16.3).

The number of chromosomes in a species is the same in all of its body cells. There are 46 chromosomes in each of your liver cells, in every nerve cell, skin cell and so on.

The chromosomes are always in pairs (Figure 16.3), for example, two long ones, two short ones, two medium ones. This is because when the zygote is formed, one of each pair comes from the male gamete and one from the female gamete. Your 46 chromosomes consist of 23 from your mother and 23 from your father.

The chromosomes of each pair are called homologous chromosomes.



▲ **Figure 16.3** Chromosomes of different species. **Note:** The chromosomes are always in pairs

Mitosis

Key definitions

Mitosis is nuclear division giving rise to **genetically identical** cells in which the chromosome number is maintained.

FOCUS POINTS

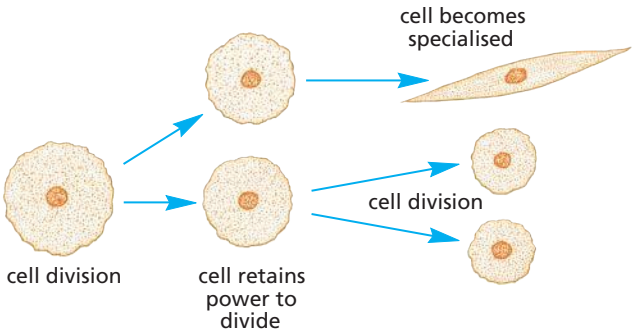
- ★ What is mitosis?
- ★ What is the role of mitosis in growth, repair of damaged tissues, replacement of cells and asexual reproduction?
- ★ What happens to the chromosomes before mitosis?
- ★ What happens to chromosomes during mitosis?
- ★ What are stem cells?
- ★ What are cancers?

The process of mitosis is important in growth. We all started off as a single cell (a zygote). That cell divided into two cells, then four and so on, to create the organism we are now, made up of millions of cells. Cells have a limited life; they wear out or become damaged, so they need to be replaced constantly. The processes of growth, repair and replacement of worn out cells all depend on mitosis. Organisms that reproduce asexually also use mitosis to make more cells.

Cell division

When plants and animals grow, their cells increase in number by dividing. Examples of growing regions are the ends of bones, layers of cells in the skin, root tips and buds (see Figure 16.7). Before cell division by mitosis begins, exact copies of all the chromosomes are made, each forming two parallel strands. The process of copying is called replication because each chromosome makes a replica (exact copy) of itself. During mitosis, the copies of the chromosomes separate, maintaining the chromosome number in each daughter cell that is formed. So, mitosis of a human cell with 46 chromosomes will result in the formation of two identical daughter cells, each with 46 chromosomes.

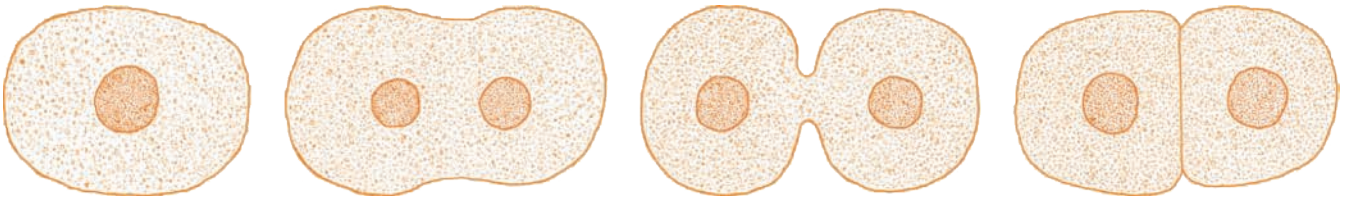
Each cell divides to produce two daughter cells. Both daughter cells may divide again, but usually one of the cells grows and changes its shape and structure. In this way it becomes adapted to do one specific job – in other words, it becomes **specialised** (Figure 16.4). At the same time, it loses its ability to divide any more. The other cell is still able to divide, so it continues the growth of the tissue. So, growth is the result of cell division, followed by cell enlargement and, in many cases, cell specialisation.



▲ **Figure 16.4** Cell division and specialisation. Cells that keep the ability to divide are sometimes called stem cells

The process of cell division in an animal cell is shown in Figure 16.5. The events in a plant cell are shown in Figures 16.6 and 16.7. The presence of the cell wall prevents the cytoplasm being pinched off in the middle. A new wall must be formed between the two daughter cells. Also, a new vacuole must form.

Organelles like mitochondria and chloroplasts can divide and are shared between the daughter cells at cell division.



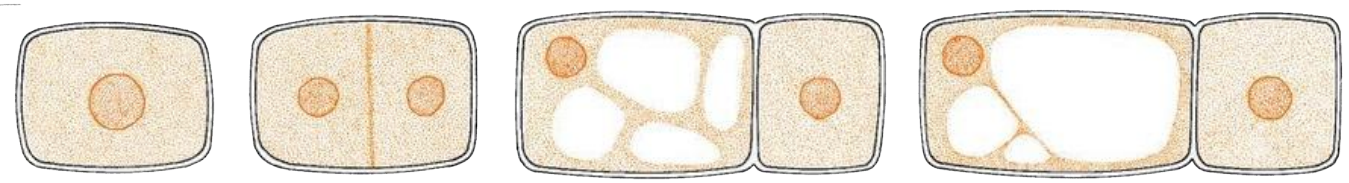
(a) Animal cell about to divide.

(b) The nucleus divides first.

(c) The daughter nuclei separate and the cytoplasm pinches off between the nuclei.

(d) Two cells are formed – one may keep the ability to divide and the other may become specialised.

▲ **Figure 16.5** Cell division in an animal cell



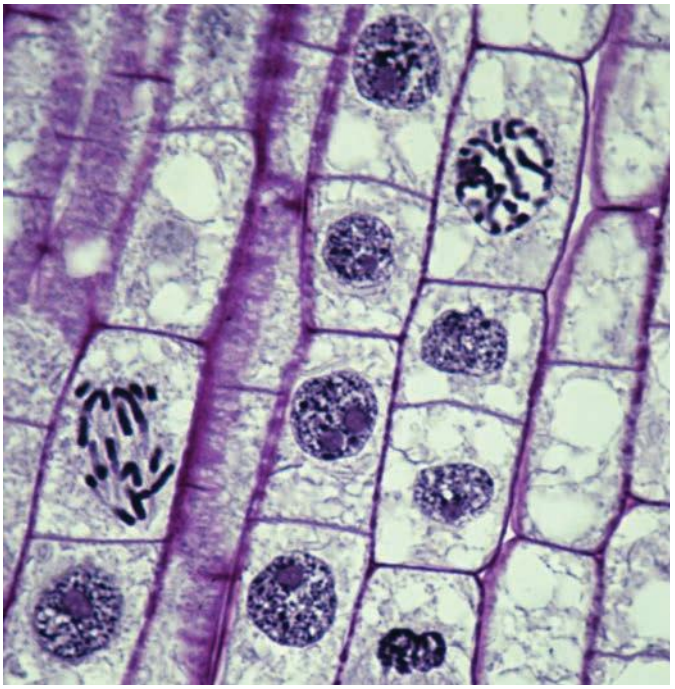
(a) A plant cell about to divide has a large nucleus and no vacuole.

(b) The nucleus divides first. A new cell wall develops and separates the two cells.

(c) The cytoplasm adds layers of cellulose on each side of the new cell wall. Vacuoles form in the cytoplasm of one cell.

(d) The vacuoles join up to form one vacuole. This takes in water and makes the cell bigger. The other cell will divide again.

▲ **Figure 16.6** Cell division in a plant cell



▲ **Figure 16.7** Cell division in an onion root tip (×250). The nuclei are stained blue. Most of the cells have just completed cell division

Stem cells

Key definitions

Stem cells are unspecialised cells that divide by mitosis to produce daughter cells that can become specialised for specific functions.

Recent developments in tissue culture (see 'Going further' on page 250) have involved stem cells. Stem cells are unspecialised cells in the body. They divide by mitosis to produce daughter cells that can become specialised for specific functions. Examples are the basal cells of the skin ('Homeostasis' in Chapter 14), which keep dividing to make new skin cells, and cells in the red bone marrow, which constantly divide to produce the whole range of blood cells ('Blood' in Chapter 11).

Normally this type of stem cell can only produce one type of tissue: epidermis, blood, muscle, nerves, etc. Even so, culture of these stem cells could lead to effective therapies by introducing healthy stem cells into the body to take over the function of diseased or damaged cells.

Going further

Cells taken from early embryos (embryonic stem cells) can be stimulated to develop into almost any kind of cell, but there are ethical objections to using human embryos for this purpose. However, scientists have learned how to stimulate brain stem cells to become muscle or blood cells. Liver cells have been cultured from blood stem cells. Scientists have also succeeded in reprogramming skin cells to develop into other types of cell, like nerve cells. Bone marrow cells are used regularly to treat patients with leukaemia (cancer of white blood cells). The use of adult stem cells does not have the ethical problems of embryonic stem cells, because cells that could become whole organisms are not being destroyed.

Cancer

Cancers form by stimulating uncontrolled cell division in the affected tissue (see the section on mutations in Chapter 17). For example, skin cancer results from uncontrolled cell division in the basal layer of the skin. Cells usually divide at the right rate to replace old and damaged cells. However, sometimes the signals the cells produce to trigger cell division become faulty. This faulty signalling can result in too much cell division and a lump, known as a tumour, develops.

Test yourself

1 Define the term *mitosis*.

2 a Describe what must happen in a cell before mitosis can take place.
  b Outline what happens during mitosis.
  c In what way is mitosis in a plant cell different from mitosis in an animal cell?

3 a Explain how stem cells are different from other body cells.
  b List two sources of stem cells.

Meiosis

FOCUS POINTS

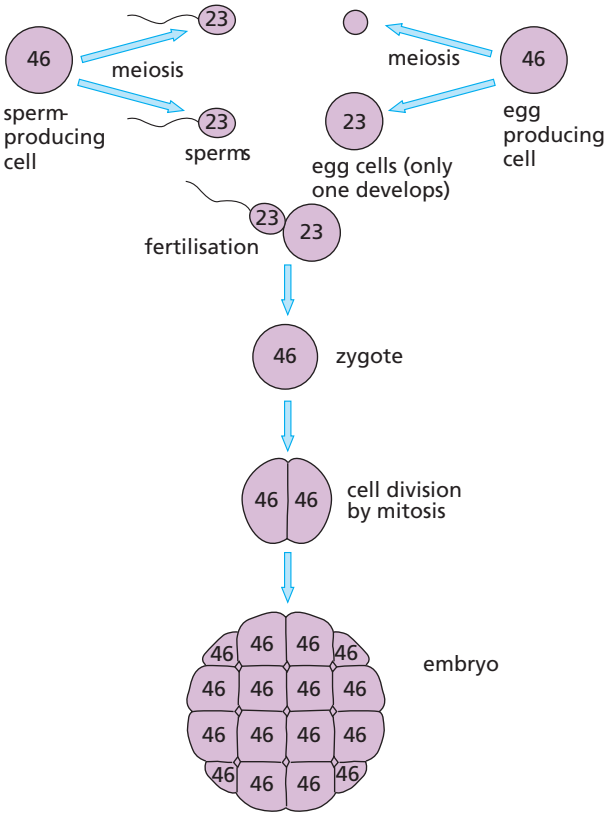
- ★ How is meiosis involved in the production of gametes?
- ★ What is meiosis?

Key definitions

Meiosis is a reduction division in which the chromosome number is halved from diploid to haploid, resulting in genetically different cells.

Meiosis takes place in the testes and ovaries of mammals, and the **anthers** and **ovules** of flowering plants. The cells formed are gametes (sperm and egg cells in mammals; ovule and **pollen** grain nuclei in flowering plants). Gametes are different from other cells because they have half the normal number of chromosomes (they are haploid).

When a female gamete is fertilised by a male gamete, the fertilised cell produced is diploid. So, the gametes must each contain only half the diploid number of chromosomes, otherwise the chromosome number would double each time an organism reproduced sexually. Each human sperm cell contains 23 chromosomes and each human egg cell has 23 chromosomes. When the sperm and egg cell fuse at fertilisation the diploid number of 46 (23 + 23) chromosomes is produced (Figure 16.8).



▲ **Figure 16.8** Chromosomes in gamete production and fertilisation

Table 16.1 compares meiosis and mitosis.

▼ **Table 16.1** Mitosis and meiosis compared

Meiosis	Mitosis
occurs in the final stages of cell division leading to production of gametes	occurs during cell division of somatic (body) cells
only half the chromosomes are passed on to the daughter cells, i.e. the haploid number of chromosomes	a full set of chromosomes is passed on to each daughter cell; this is the diploid number of chromosomes
homologous chromosomes and their genes are randomly assorted between the gametes	the chromosomes and genes in each daughter cell are identical
new organisms produced by meiosis in **sexual reproduction** will show variations from each other and from their parents	if new organisms are produced by mitosis in **asexual reproduction** (e.g. bulbs) they will all be like each other and their parents; they are said to be 'clones'

Test yourself

4 Construct a table to compare where meiosis happens in the human body and in a flowering plant and what the products of meiosis are in these organisms.

5 State two ways in which the products of meiosis are different from the products of mitosis.

Asexual reproduction

FOCUS POINTS

- ★ What is asexual reproduction?
- ★ How can you identify asexual reproduction?
- ★ What are the advantages and disadvantages of asexual reproduction to a population of a species?

Key definitions

Asexual reproduction is the process resulting in the production of genetically identical offspring from one parent.

Asexual means *without sex*. This method of reproduction does not involve gametes (sex cells).

In the single-celled Protoctista or in bacteria, the cell simply divides into two and each new cell becomes an independent organism.

In more complex organisms, part of the body may grow and develop into a separate individual. For example, a small piece of stem planted in the soil may form roots and grow into a complete plant.

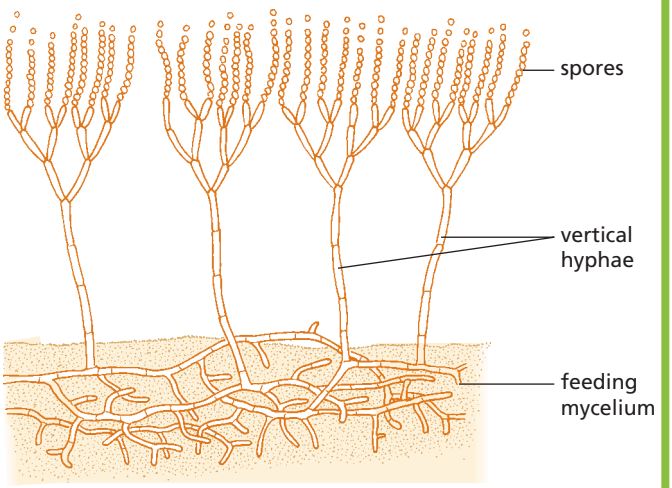
Bacteria reproduce by cell division (fission). Any bacterial cell can divide into two and each daughter cell becomes an independent bacterium (Figure 1.11 on page 6). In some cases, this cell division can take place every 20 minutes so that, in a very short time, a large colony of bacteria can be produced. This is one reason why a small number of bacteria can heavily contaminate our food products (see Chapter 12). This kind of reproduction, without the formation of gametes (sex cells), is called asexual reproduction.

Going further

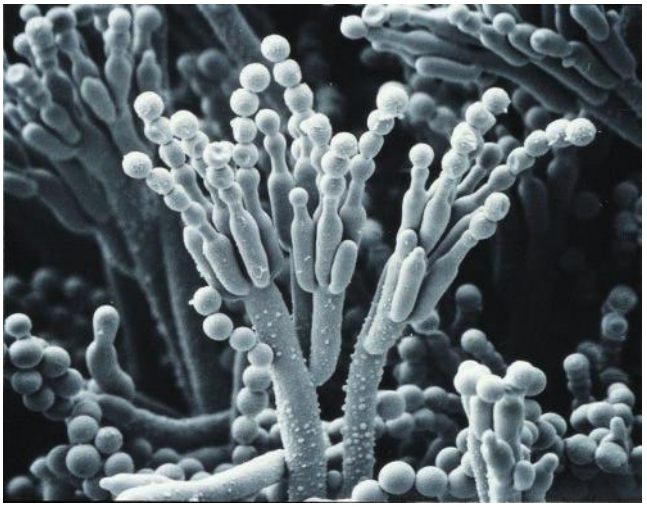
Asexual reproduction in fungi

Fungi have sexual and asexual methods of reproduction. In the asexual method they produce single-celled, haploid spores. These are dispersed, often by air currents, and they grow new hyphae if they reach a suitable location. The hyphae develop into a mycelium (see Figures 2.31 and 2.32, pages 36 and 37).

Penicillium and *Mucor* are examples of mould fungi that grow on decaying food or vegetable matter. *Penicillium* is a genus of mould fungi that grows on decaying vegetable matter, damp leather and citrus fruits. The mycelium grows over the food, digesting it and absorbing nutrients. Vertical hyphae grow from the mycelium and, at their tips, produce chains of spores (Figures 16.9 and 16.10). These give the colony a blue-green colour and a powdery appearance (see Figure 19.12 on page 333). The spores are dispersed by air currents and, if they reach a suitable substrate, grow into a new mycelium.



▲ **Figure 16.9** *Penicillium sp.*



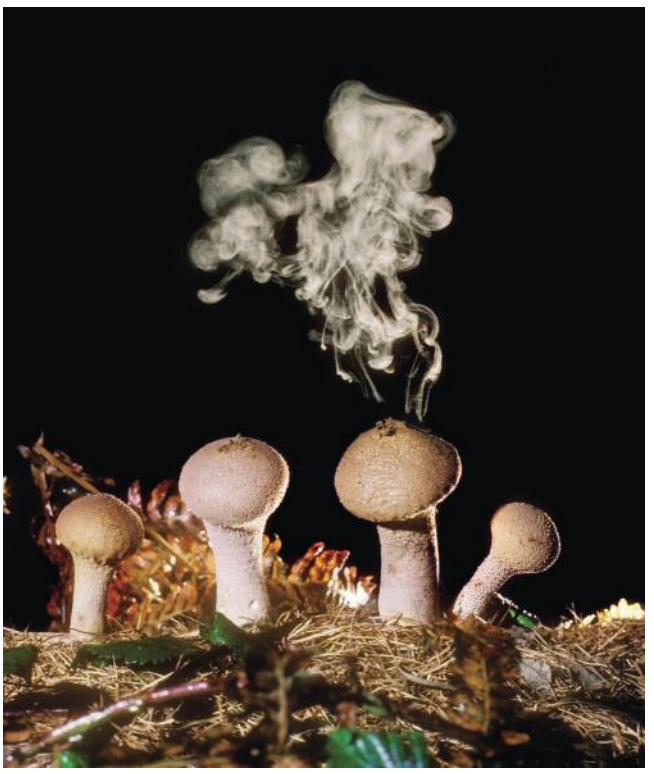
▲ **Figure 16.10** Scanning electron micrograph of *Penicillium* spores

Mucor feeds, grows and reproduces in a similar way to *Penicillium*, but *Mucor* produces spores in a slightly different way. Instead of chains of spores at the tips of the vertical hyphae, *Mucor* forms spherical sporangia. Each of these contains hundreds of spores (Figure 16.11). These are dispersed on the feet of insects or by the splashes of rain drops.

The gills on the lower side of a mushroom or toadstool (Figures 16.12) produce spores. Puffballs release clouds of spores (Figure 16.13).

▲ **Figure 16.11** Asexual reproduction in *Mucor*. The black spheres are sporangia that have not yet released their spores (×160)

▲ **Figure 16.12** Toadstools growing on a fallen tree. The toadstools are the reproductive structures that produce spores. The feeding hyphae are inside the tree, digesting the wood



▲ **Figure 16.13** Puffball dispersing spores. When a raindrop hits the ripe puffball, a cloud of spores is released into the air

Asexual reproduction in flowering plants (vegetative propagation)

All flowering plants reproduce sexually, which is why they have flowers. However, many of them also have asexual methods.

Several of these asexual methods (also called vegetative propagation) are described below. When asexual reproduction takes place naturally, it usually results from the growth of a lateral bud on a stem which is close to, or under, the soil. Instead of just making a branch, the bud produces a complete plant

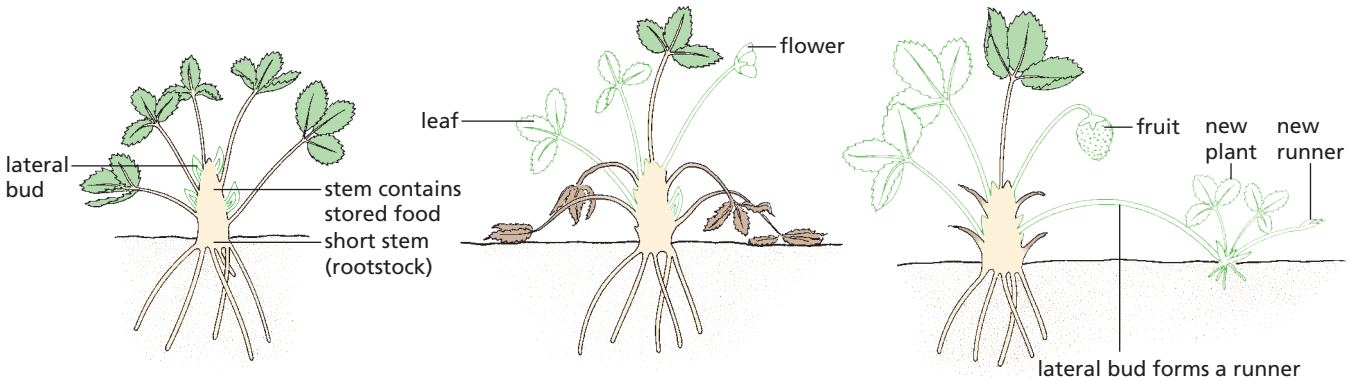
with roots, stem and leaves. When the old stem dies, the new plant is independent of the parent that produced it.

An unusual method of vegetative propagation is shown by *Bryophyllum* (Figure 16.14).

▲ **Figure 16.14** *Bryophyllum*. The plantlets are produced from the leaf margin. When they fall to the soil below, they grow into independent plants

Runners and rhizomes

The flowering shoots of plants like the strawberry and the creeping buttercup are very short and mostly below ground. The stems of shoots like these have leaves and flowers. After the main shoot has flowered, the lateral buds produce long shoots, which grow horizontally over the ground (Figure 16.15). These shoots are called runners. They have only small, scale-leaves at their nodes and very long internodes. At each node there is a bud that can produce a shoot and roots as well. So, a complete plant may develop and take root at the node. For a while, the parent plant provides it with nutrients through the runner. Eventually, the runner dries up and withers, leaving an independent daughter plant growing a short distance away from the parent. In this way a strawberry plant can produce many daughter plants by asexual reproduction in addition to producing seeds.

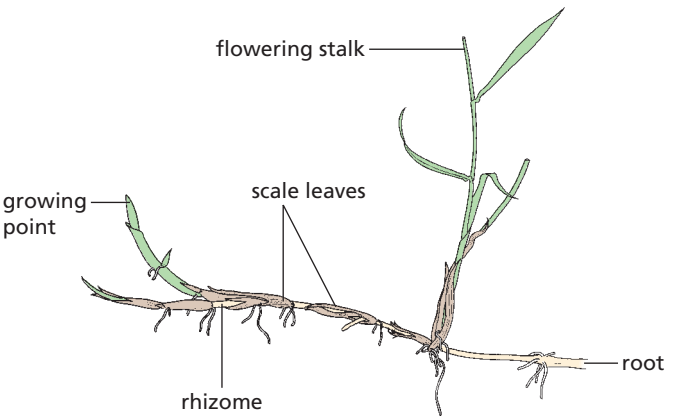


▲ **Figure 16.15** Strawberry runner developing from the parent plant

In many plants, horizontal shoots arise from lateral buds near the stem base and grow under the ground. These underground horizontal stems are called rhizomes. Buds develop, which may produce shoots above the ground. The shoots become independent plants when the connecting rhizome dies.

Many grasses reproduce using rhizomes; the couch grass (Figure 16.16) is a good example. Even a small piece of rhizome, provided it has a bud, can produce a new plant.

In bracken, a type of fern, all of the stem is horizontal and below ground. The bracken fronds you see in summer are produced from buds on a rhizome below the soil.



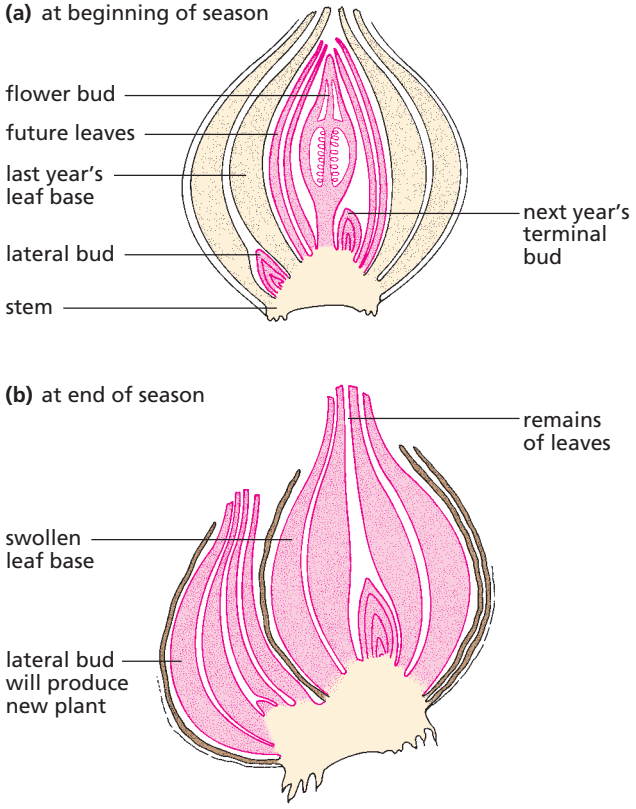
▲ **Figure 16.16** Couch grass rhizome

Bulbs and corms

Bulbs like those of the daffodil and lily are very short shoots. The stem is only a few millimetres long and the leaves that develop around the stem are thick and fleshy with stored food.

In spring, the stored food is used by a rapidly growing terminal bud. It produces a flowering stalk and a small number of leaves. During the growing season, food made in the leaves is sent to the leaf bases and stored. The leaf bases swell and form a new bulb ready for growth in the next year.

Asexual reproduction occurs when some of the food is sent to a lateral bud as well as to the leaf bases. The lateral bud grows inside the parent bulb and, next year, will produce an independent plant (Figure 16.17).



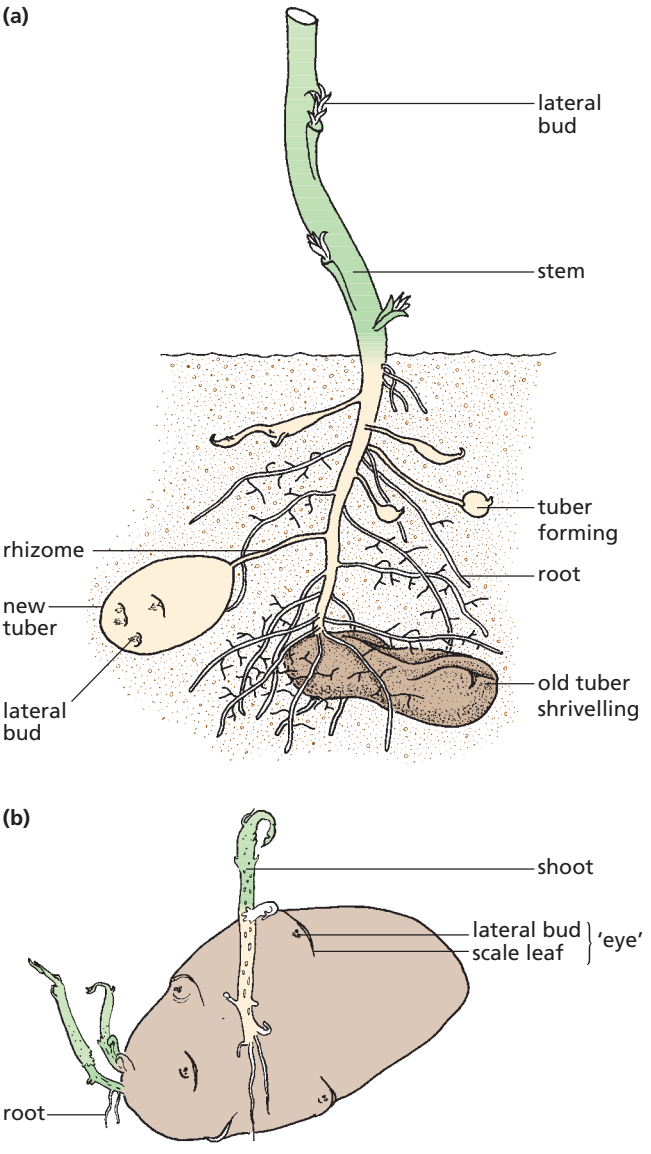
▲ **Figure 16.17** Daffodil bulb; vegetative reproduction

The corms of crocuses and *Colocasia* have life cycles like bulbs but it is the stem, rather than the leaf bases, which swells with stored food. Asexual reproduction takes place when a lateral bud on the short, fat stem grows into an independent plant.

In many cases the organs associated with asexual reproduction also serve as food stores. Food in the storage organs enables very rapid growth in the spring. *Colocasia esculenta*, also called Taro, is a perennial, tropical plant often grown as a root vegetable for its edible, starchy corm.

Many of the spring and early summer plants around the world have bulbs, corms, rhizomes or tubers.

Potatoes are stem tubers. Lateral buds at the base of the potato shoot produce underground shoots (rhizomes). These rhizomes swell up with stored starch and form tubers (Figure 16.18(a)). Because the tubers are stems, they have buds. If the tubers are left in the ground or transplanted, the buds will produce shoots, using food stored in the tuber (Figure 16.18(b)). In this way, the potato plant reproduces asexually.



▲ **Figure 16.18** Stem tubers growing on a potato plant and a potato tuber sprouting

Going further

Artificial propagation

Plant growers make use of asexual reproduction in order to produce fresh stocks of plants. This can be done naturally, for example, by planting potatoes. There are also methods that would not occur naturally in the plant's life cycle. Two methods of artificial propagation are by taking cuttings and by tissue culture.

Cuttings

It is possible to produce new individuals from some plants by putting the cut end of a shoot into water or moist earth. Roots (Figure 16.19) grow from the base of the stem into the soil while the shoot continues to grow and produce leaves.

▲ **Figure 16.19** Roots growing on a shoot cutting of a geranium plant

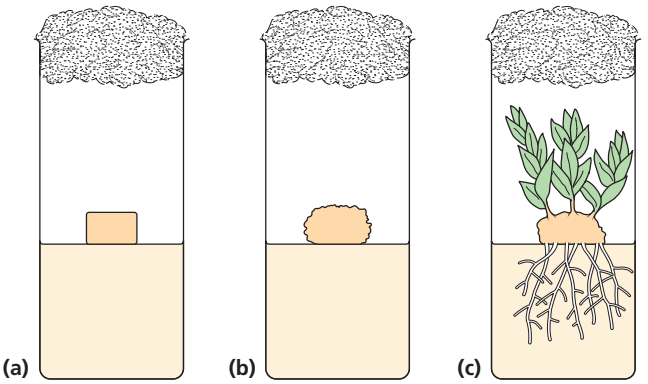
To make the process more reliable, the cut end of the stem can be treated with a rooting growth substance (a type of auxin – see 'Tropic responses' in Chapter 15) to encourage root growth. Evaporation from the shoot is reduced by covering it with polythene or a glass jar.

Tissue culture

Once a cell has become part of a tissue it usually loses the ability to reproduce. However, the nucleus of any cell in a plant still holds all the instructions for reproduction (Chapter 17) for making a complete plant. In certain situations they can be brought back into action.

In laboratory conditions, single plant cells can be stimulated to divide and grow into complete plants. One method is to take small pieces of plant tissue from a root or stem and treat it with enzymes to separate it into individual cells. The cells are then provided with a plant growth substance, which stimulates cell division and goes on to form roots, stems and leaves.

An alternative method is to start with a small piece of tissue and place it on a nutrient jelly. Cells in the tissue start to divide and produce many cells, forming a shapeless mass called a callus. If the callus is then provided with the appropriate growth substances it develops into a complete plant (Figure 16.20).



▲ **Figure 16.20** Propagation by tissue culture using nutrient jelly

Using the technique of tissue culture, large numbers of plants can be produced from small amounts of tissue (Figure 16.21), and they have the advantage of being free from fungal or bacterial infections. The plants produced in this way form clones, because they have been produced from a single parent plant.

▲ **Figure 16.21** Tissue culture. Plants grown from small amounts of unspecialised tissue on an agar culture medium

Asexual reproduction in animals

Some species of invertebrate animals can reproduce asexually.

Hydra is a small animal, 5–10 mm long, which lives in ponds attached to pondweed. It traps small animals with its tentacles, swallows and digests them. *Hydra* reproduces sexually by releasing its male and female gametes into the water, but it also has an asexual method, which is shown in Figure 16.22.

a a group of cells on the column start dividing rapidly and produce a swelling
b the swelling develops tentacles
c the daughter *Hydra* pulls itself off the parent
d the daughter becomes an independent animal
e *Hydra* with bud

▲ **Figure 16.22** Asexual reproduction in *Hydra*

The advantages and disadvantages of asexual reproduction

The advantages and disadvantages of asexual reproduction discussed refer to flowering plants. However, the points made are also relevant to most forms of asexual reproduction.

In asexual reproduction no gametes are involved, and all the new plants are produced by cell division (mitosis) from only one parent. As a result, they are **genetically identical**; there is no variation. A population of genetically identical individuals produced from a single parent is called a clone. This has the advantage of preserving the good characteristics of a successful species from generation to generation. The disadvantage is that there is no variation for **natural selection** (Chapter 17) to act on in the process of evolution.

In crop production, asexual reproduction is used to keep desirable qualities in crops: the good characteristics of the parent are passed on to all the offspring and stable varieties are created. Another advantage is that it results in a uniform crop. With a flower like a lily, the bulbs produced can be guaranteed to produce the same shape and colour of flower from one generation to the next. In some cases, like tissue culture, the young plants grown can be transported much more cheaply than, for example, potato tubers. Potato tubers are much heavier and more bulky. Growth of new plants by asexual reproduction is usually a quick process.

In natural conditions in the wild it can be a disadvantage to have no variation in a species. If the climate or other conditions change and a plant produces asexually it has no resistance to a particular disease, and so the whole population could be wiped out.

Dispersal

A plant that reproduces asexually will already be growing in a favourable position, so all the offspring will find themselves in a suitable environment. However, there is no dispersal mechanism and the plants will grow in dense colonies, competing with each other for water and ions. This can be an advantage because dense colonies leave little room for competitors of other species.

As mentioned before, most plants that reproduce asexually also produce flowers and seeds. In this way they can colonise habitats further away from the parent plant.

Food storage

The store of food in tubers, tap roots, bulbs, etc. allows the plants to grow rapidly as soon as conditions become suitable. Early growth allows the plant to flower and produce seeds before it has to compete strongly with other plants (for water, mineral ions and light). This must be especially important in woods in summer when the leaf canopy stops much light from reaching the ground and the tree roots tend to take in water from the soil over a wide area.

▼ **Table 16.2** Summary: advantages and disadvantages of asexual reproduction

Advantages	Disadvantages
No mate is needed. No gametes are needed. All the good characteristics of the parent are passed on to the offspring. This results in uniform crops and stable varieties. Where there is no dispersal (e.g. with potato tubers), offspring will grow in the same favourable environment as the parent. Plants that reproduce asexually usually store large amounts of food that allow rapid growth when conditions are suitable.	There is little variation created, so adaptation to a changing environment (evolution) is unlikely. If the parent has no resistance to a particular disease, none of the offspring will have resistance. This could affect all of a crop. Lack of dispersal (e.g. with potato tubers) can lead to **competition** for nutrients, water and light.

Test yourself

6 Which of the following do not play a part in asexual reproduction?
mitosis, gametes, meiosis, cell division, chromosomes, zygote

7 The plants that survive a fire on the land are often those that have an underground stem (rhizome), for example, ferns. Suggest a reason why they survive.

Sexual reproduction

FOCUS POINTS

- ★ What is sexual reproduction?
- ★ Are the nuclei of gametes haploid and is the nucleus of a zygote diploid?
- ★ What is fertilisation?
- ★ What are the advantages and disadvantages of sexual reproduction to a population of a species?

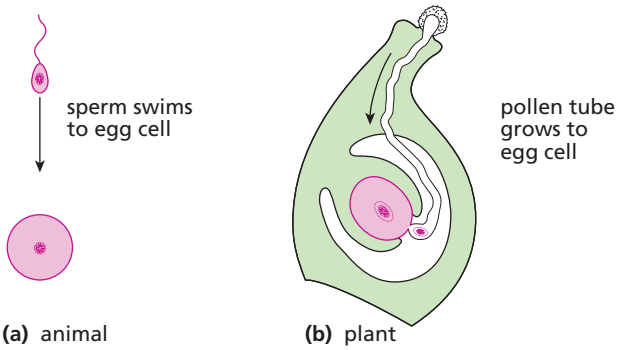
Key definitions

Sexual reproduction is a process involving the fusion of haploid nuclei (fertilisation) to form a diploid zygote and the production of genetically different offspring.

The next statements apply equally to plants and animals. Sexual reproduction involves the production of sex cells. These sex cells are called gametes and they are made in reproductive organs. The process of cell division that produces the gametes is called meiosis. In sexual reproduction, the male and female gametes come together and join or **fuse**. This means that their nuclei and cytoplasm fuse to form a single cell called a zygote. The zygote then grows into a new individual.

In flowering plants, the male gametes are found in pollen grains and the female gametes, called egg cells, are present in ovules. In animals, male gametes are sperm and female gametes are eggs. Details of fertilisation are given later in this chapter.

In both plants and animals, the male gamete is microscopic and mobile (i.e. can move from one place to another). The sperm swim to the egg cell; the pollen cell moves down the **pollen tube** (Figure 16.23). The female gametes are always larger than the male gametes and are not mobile. Pollination in seed-bearing plants and mating in most animals bring the male and female gametes close together.



▲ **Figure 16.23** The male gamete is small and mobile; the female gamete is larger

Chromosome numbers

In normal body cells (somatic cells) the chromosomes are present in the nucleus in pairs. Humans, for example, have 46 chromosomes: 23 pairs. Maize (sweetcorn) has 10 pairs. This is known as the **diploid** number. When gametes are formed, the number of chromosomes in the nucleus of each sex cell is halved. This is the **haploid** number. During fertilisation, when the nuclei of the sex cells fuse, a zygote is formed. It gains the chromosomes from both gametes, so it is a diploid cell (see Chapter 17).

The advantages and disadvantages of sexual reproduction

In plants, the gametes may come from the same plant or from different plants of the same species. In either case, the production and then fusion of gametes produce a range of variation among the offspring (see Chapter 17). This results from new combinations of characteristics, for example, petal colour of one parent combined with fruit size of the other. It may also be the result of spontaneous changes in the gametes when they are produced.

Variation can have its disadvantages: some combinations will produce less successful individuals. However, there are likely to be some more successful combinations that have greater survival value or produce individuals that can succeed in new or changing environments.

In a population of plants that have been produced sexually, there is a chance that at least some of the offspring will have resistance to disease. These plants will survive and produce further offspring with disease resistance.

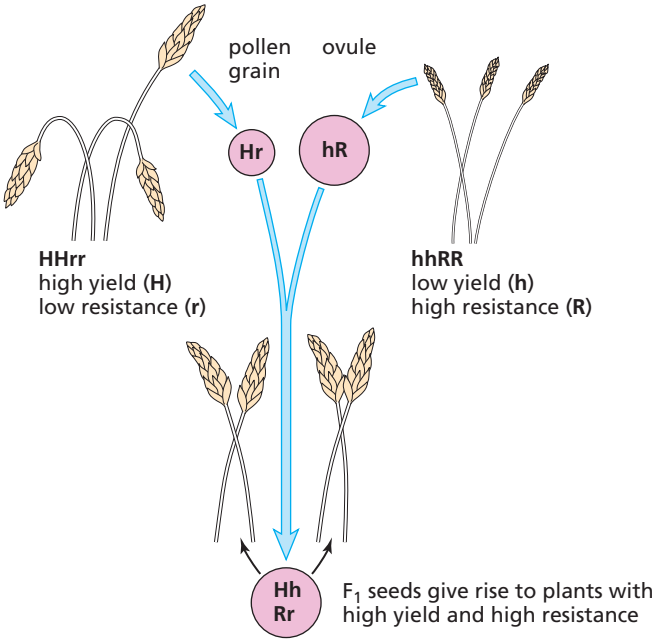
The seeds produced as a result of sexual reproduction will be scattered over quite a wide range. Some will land in unsuitable environments, for example, lacking light or water. These seeds will not germinate. However, most methods of seed dispersal result in some of the seeds forming populations in new habitats, helping the species to colonise new areas.

The seeds produced by sexual reproduction all contain some stored food, but it is quickly used up during **germination**, which only produces a small plant. It takes a long time for a seedling to become established and eventually produce seeds of its own.

Sexual reproduction is used to produce new varieties of animals and plants by cross-breeding.

Cross-breeding

It is possible for biologists to use their knowledge of genetics (see 'Single-factor inheritance' in Chapter 17) to produce new varieties of plants and animals. For example, one variety of wheat may produce a lot of grain but is not resistant to a fungal disease. Another variety may be resistant to the disease but has only a poor yield of grain. If these two varieties are cross-pollinated (Figure 16.24), the F1 (which means *first filial generation*) offspring should be disease-resistant and give a good yield of grain (assuming that the useful characteristics are controlled by **dominant** genes).



▲ **Figure 16.24** Combining useful characteristics

A long-term disadvantage of **selective breeding** is the loss of variability. By removing all the offspring who do not bear the desired characteristics, many genes are lost from the population. In the future, when new combinations of genes are required, some of the potentially useful ones may no longer be available.

You will find more information on cross-breeding in 'Selection', Chapter 17.

▼ **Table 16.3** Summary: advantages and disadvantages of sexual reproduction

Advantages	Disadvantages
There is variation in the offspring, so adaptation to a changing or new environment is likely, enabling survival of the species.	Two parents are usually needed (though not always – some plants can self-pollinate).
New varieties can be created, which may have resistance to disease.	Growth of a new plant to maturity from a seed is slow.
In plants, seeds are produced, which allow dispersal away from the parent plant, reducing competition.	

Sexual reproduction in plants

FOCUS POINTS

- ★ Where are the following parts of an insect-pollinated flower: the sepals, petals, stamens (filaments, anthers), carpels (style, stigma, ovary and ovules)? What do they look like and what are their functions?
- ★ Where are the anthers and stigmas of a wind-pollinated flower and what do they look like?
- ★ What are the differences between the flowers and the pollen grains of insect-pollinated and wind-pollinated flowers?
- ★ What is pollination?
- ★ What is self-pollination?
- ★ What is cross-pollination?
- ★ What are the potential effects of self-pollination and cross-pollination on a population, in terms of variation, capacity to respond to changes in the environment and reliance on pollinators?
- ★ What happens when fertilisation occurs in a plant?
- ★ What happens during germination?
- ★ What is the structure of a seed?
- ★ How and why are fruits and seeds dispersed?
- ★ What are the environmental conditions that affect germination of seeds?

Key definitions

Pollination is the transfer of pollen grains from an anther to a **stigma**.

Flowers are reproductive structures; they contain the reproductive organs of the plant. The male organs are the **stamens**, which produce pollen. The female organs are the carpels. After fertilisation, part of the carpel becomes the fruit of the plant and contains the seeds. In the flowers of most plants there are stamens and carpels. So, these flowers are both male and female.

Some species of plants have unisexual flowers. This means that any one flower will contain either stamens or carpels but not both. Sometimes both male and female flowers are present on the same plant (e.g. the hazel, which has male and female flowers on the same tree). In the willow tree, on the other hand, the male and female flowers are on different trees.

The pollen grain grows a microscopic tube, which carries the male gamete the last few millimetres to reach the female gamete for fertilisation. The zygote then grows to form the seed. These processes are all described in more detail later in this chapter.

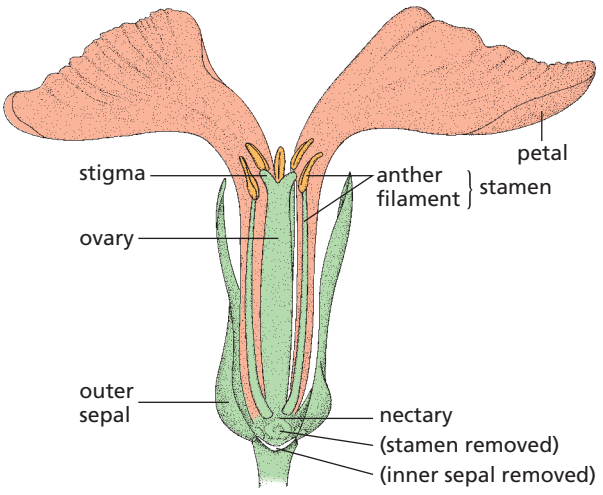
Flower structure

The basic structure of a flower is shown in Figures 16.26 and 16.28.

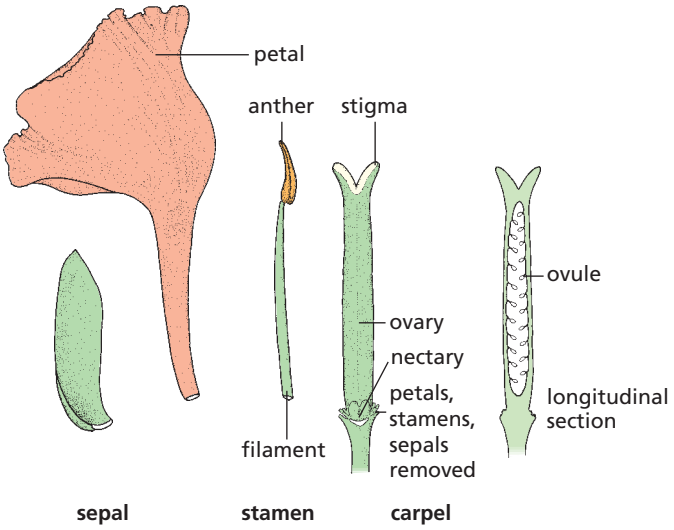
Petals

Petals are usually brightly coloured and sometimes scented. They are arranged in a circle (Figure 16.25) or a cylinder. Most flowers have from four to ten petals. Sometimes they are joined to form a tube (Figures 16.27 and 16.28) and the individual petals can no longer be distinguished. The colour and scent of the petals attract insects to the flower; the insects may pollinate the flower.

The flowers of grasses and many trees do not have petals. Instead they have small, leaf-like structures that surround the reproductive organs (Figures 16.35 and 16.40).

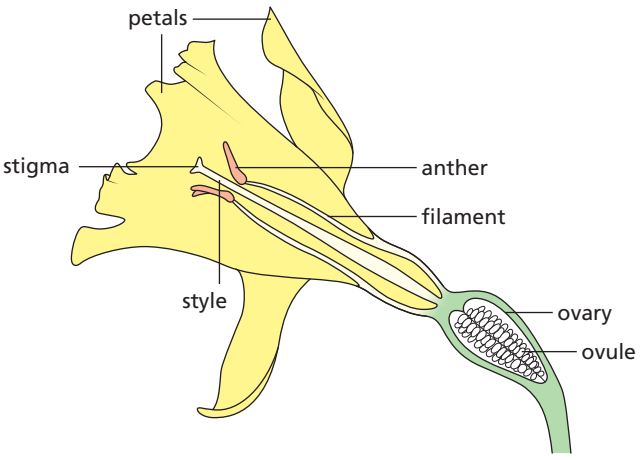


▲ **Figure 16.25** Wallflower; structure of flower (one sepal, two petals and stamen removed)



▲ **Figure 16.26** Floral parts of wallflower

▲ **Figure 16.27** Daffodil flower cut in half. The inner petals form a tube. Three stamens are visible round the long style and the ovary contains many ovules



▲ **Figure 16.28** Daffodil flower. In daffodils, lilies, tulips, etc. (monocots) there is no distinction between sepals and petals

Sepals

Outside the petals is a ring of **sepals**. They are often green and much smaller than the petals. They may protect the flower when it is in the bud.

Stamens

The stamens are the male reproductive organs of a flower. Each stamen has a stalk called the filament with an anther on the end. Flowers like the Tea flower and Sacred lotus have many stamens; others like the tulip have a small number, often the same as the number of petals or sepals. Each anther is made of four pollen sacs in which the pollen grains are produced by cell division. When the anthers are ripe, the pollen sacs split open and release their pollen (see Figure 16.33).

Pollen

Pollen contains the male gamete. **Insect-pollinated flowers** tend to produce smaller amounts of pollen grains (Figure 16.29(a)). These are often round and sticky, or covered in tiny spikes to attach to the furry bodies of insects.

Wind-pollinated flowers tend to produce larger amounts of smooth, light pollen grains (Figure 16.29(b)). These features mean that they are easily carried by the wind. Large amounts are needed because much of the pollen is lost so there is a low chance of it reaching another flower of the same species.

Carpels

These are the female reproductive organs. Flowers like the buttercup and blackberry have many carpels while others, like the lupin and Hibiscus, have a single carpel. Each carpel consists of an ovary, bearing a **style** and a stigma.

(a) insect-borne pollen grains **(b)** wind-borne pollen grains

▲ **Figure 16.29** Pollen grains

Inside the ovary there are one or more ovules. Each blackberry ovary contains one ovule, but the wallflower ovary contains several. The ovule will become a seed, and the whole ovary will become a fruit. (In biology, a fruit is the fertilised ovary of a flower, not always something to eat.)

The style and stigma are attached to the top of the ovary. The stigma has a sticky surface and pollen grains will stick to it during pollination. The style may be quite short (e.g. wallflower, Figure 16.25) or very long (e.g. daffodil, Figures 16.27 and 16.28).

Receptacle

The flower structures just described are all attached to the expanded end of a flower stalk. This is called the receptacle and, in a few cases after fertilisation, it becomes fleshy and edible (e.g. apple and pear).

The main functions of the parts of a flower are summarised in Table 16.4.

▼ **Table 16.4** The main functions of the parts of a flower

Part	Function
petal	often large and coloured to attract insects
sepal	protects the flower while in bud
stamen	the male reproductive part of the flower, made up of the anther and the filament
anther	contains pollen sacs in which pollen grains are formed. Pollen contains male sex cells. **Note:** You need to be able to describe an anther
filament	supports the anther
carpel	the female reproductive part of the flower, made up of the stigma, style and ovary
stigma	a sticky surface that receives pollen during pollination. **Note:** You need to be able to describe a stigma
style	links the stigma to the ovary through which pollen tubes grow
ovary	contains ovules
ovule	contains a haploid nucleus, which develops into a seed when fertilised

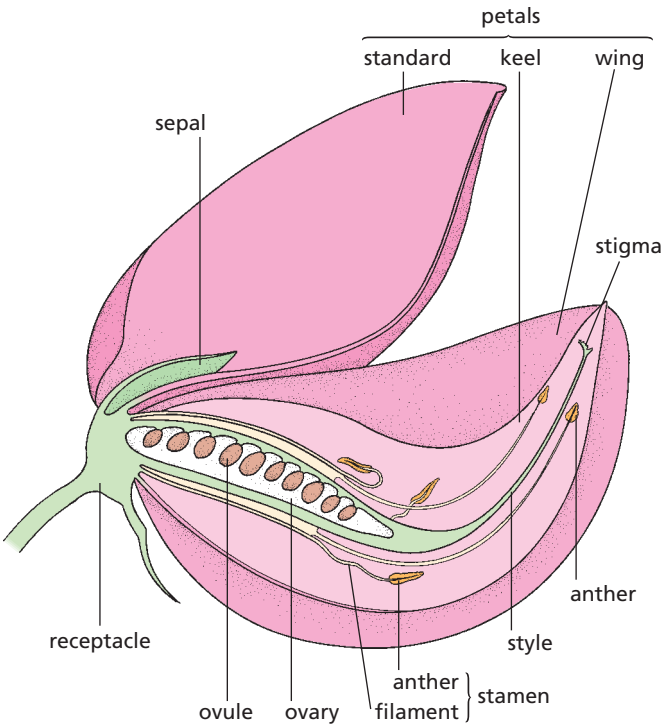
Lupin

The lupin flower is shown in Figures 16.30 to 16.32. There are five sepals, but these are joined, forming a short tube. The five petals have different shapes and sizes. The uppermost, called the standard, is held vertically. Two petals at the sides are called wings and are partly joined. Inside the wings are two more petals joined to form a boat-shaped keel.

The single carpel is long, narrow and pod shaped, with about ten ovules in the ovary. The long style ends in a stigma just inside the pointed end of the keel.

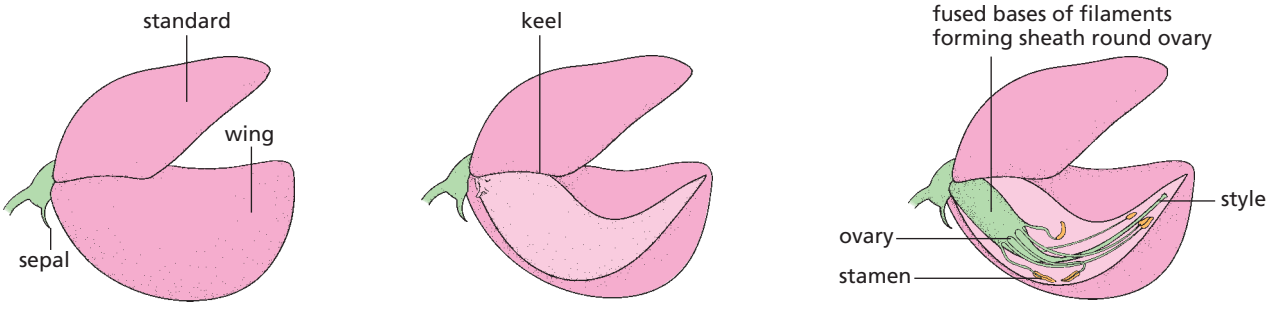
There are ten stamens: five long ones and five short ones. Their filaments are joined at the base to form a sheath around the ovary.

The flowers of peas and beans are very similar to lupin flowers.



▲ **Figure 16.30** Half-flower of lupin

The shoots or branches of a plant carrying groups of flowers are called inflorescences. The flowering shoots of the lupin in Figure 16.32 are inflorescences. Each one carries about a hundred individual flowers.



(a) intact **(b)** one wing removed **(c)** one side of keel removed

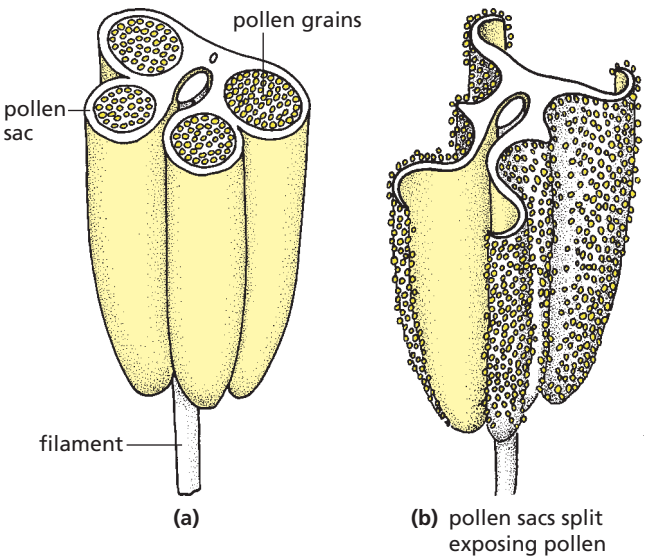
▲ **Figure 16.31** Lupin flower dissected

▲ **Figure 16.32** Lupin inflorescence. There are a hundred or more flowers in each inflorescence. The youngest flowers, at the top, have not yet opened. The oldest flowers are at the bottom and have already been pollinated

Pollination

Pollination is the transfer of pollen grains from an anther to a stigma.

The anthers split open, exposing the microscopic pollen grains (Figure 16.33). The pollen grains are then carried away on the bodies of insects, or simply blown by the wind, and may land on the stigma of another flower.

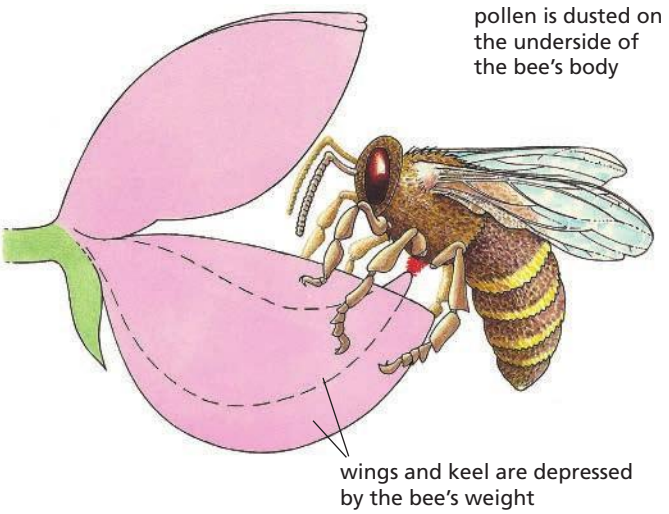


▲ **Figure 16.33** Structure of an anther (top cut off)

Insect pollination

Lupin flowers have no nectar. The bees that visit them come to collect pollen, which they take back to the hive for food. Other members of the lupin family (*Leguminosae*, e.g. clover) do produce nectar.

When a bee lands on the flower's wings, its weight pushes down these two petals and the petals of the keel. The pollen from the anthers has collected in the tip of the keel. As the petals are pressed down, the stigma and long stamens push the pollen out from the keel on to the underside of the bee (Figure 16.34). The bee, with pollen grains sticking to its body, then flies to another flower. If this flower is older than the first one, it will already have lost its pollen. When the bee's weight pushes the keel down, only the stigma comes out and touches the insect's body, picking up pollen grains on its sticky surface. Lupin and wallflower are examples of insect-pollinated flowers.



▲ **Figure 16.34** Pollination of the lupin

Practical work

Safety

- Wash your hands after handling the flower.

1 Dissection of an insect-pollinated flower

You will need a flower, a clean surface e.g. white tile, a piece of white A4 paper, a pair of forceps (tweezers), some clear adhesive tape and a pair of scissors.

- Use a single flower e.g. wallflower, buttercup or lily (not a daisy or dandelion as these are multiple flowers).
- Place the flower on the clean surface

- Refer to Figure 16.25 for the positions of the flower parts.
- Using the forceps, remove the sepals and lay them horizontally across the top of your sheet of paper.
- Tape them down, and label them. Also record the number and any special features such as colour.
- Remove the other parts of the flower in the following order, taping them down as you remove them: petals, stamens, carpel(s), stalk.

Practical work questions

1 The stamens and the carpels are the reproductive parts of the flower. What is made in
a the stamens **b** the carpels?
2 What is the function of the sepals?

Wind pollination

Grasses, cereals and many trees are pollinated by wind currents, not by insects. The flowers are often quite small with small, green, leaf-like bracts, rather than petals. They do not produce nectar. The anthers and stigma are not surrounded by the bracts, so they are exposed to the air. The pollen grains, being light and smooth, may be carried long distances by the moving air. Some of them will be trapped on the stigmas of other flowers.

In the grasses, at first, the feathery stigmas stick out of the flower and pollen grains floating in the air are trapped by them. Later, the anthers hang outside the flower (Figures 16.35 and 16.40), the pollen sacs split and the wind blows the pollen away. This sequence varies between species.

▲ **Figure 16.35** Grass flowers. **Note:** The anthers hang freely outside the bracts

If the branches of a fir tree or acacia, or the flowers of the ornamental pampas grass, are shaken, a shower of pollen can easily be seen (Figure 16.36).

Practical work

Safety

- Wash your hands after handling the flower.

2 Dissection of a wind-pollinated flower

You will need a flower, a clean surface e.g. white tile, a piece of white A4 paper, a pair of forceps (tweezers), some clear adhesive tape and a pair of scissors. A hand lens may be needed to view the flowers.

- Use a single flower which has mature stamens.
- Place the flower on the clean surface.
- Refer to Figure 16.40 for the positions of the flower parts.
- Using the forceps, remove the bracts and lay them horizontally across the top of your sheet of paper.
- Tape the bracts down, and label them. Also record the number and any special features such as colour.
- Remove the other parts of the flower in the following order, taping them down as you remove them: stamens, carpel(s), stalk.

Practical work question

3 Suggest why the stamens have long filaments.

▲ **Figure 16.36** Pollen shower from a noble fir tree

Self-pollination and cross-pollination

Self-pollination is the transfer of pollen grains from the anther of a flower to the stigma of the same flower, or a different flower on the same plant.

Cross-pollination is the transfer of pollen grains from the anther of a flower to the stigma of a flower on a different plant of the same species.

If a bee carried pollen from one of the younger flowers near the middle of a lupin plant (Figure 16.32) to an older flower near the bottom, this would be self-pollination. However, if the bee visited a separate lupin plant and pollinated its flowers, this would be cross-pollination.

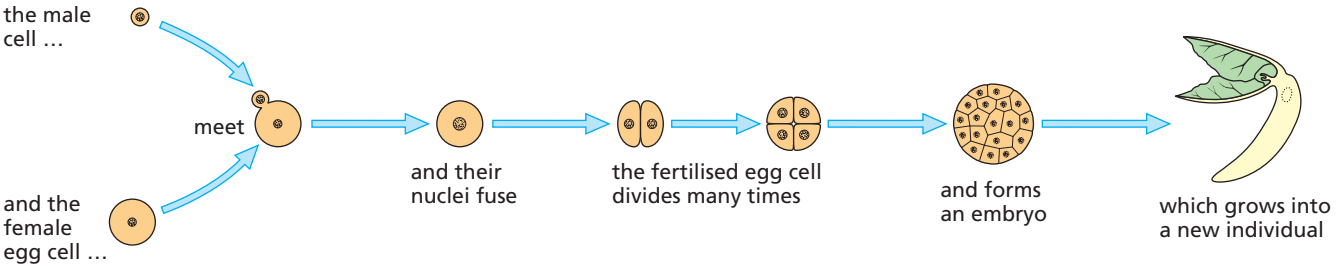
If a plant relies on self-pollination, the disadvantage will be that variation will be limited in future generations. So, those plants may not be able to adapt to changing environmental conditions. However, self-pollination can happen even if there are no pollinators, because the flower's own pollen may drop onto its stigma. This means that even if there are not many pollinators (perhaps because of the over-use of insecticides) the plant can produce seeds and prevent **extinction**.

However, cross-pollination will guarantee variation and give the plant species a better chance of adapting to changing conditions. Some plants maintain cross-pollination by producing stamens (male reproductive parts) at a different time to the carpels (female reproductive parts). However, cross-pollinated plants do rely on pollinators to carry the pollen to other plants.

Fertilisation

Pollination is complete when pollen from an anther has landed on a stigma. If the flower is to produce seeds, pollination needs be followed by a process called fertilisation. In all living organisms, fertilisation happens when a male sex cell and a female sex cell meet and join, and the nuclei *fuse*. The cell that is formed by this fusion is called a zygote, which contains the genetic material and the cytoplasm from both gametes. The zygote develops into an embryo of an animal or a plant (Figure 16.37). The sex cells of all living organisms are called gametes.

For fertilisation to occur, the nucleus of the male cell from the pollen grain needs to reach the female nucleus of the egg cell in the ovule and fuse with it.

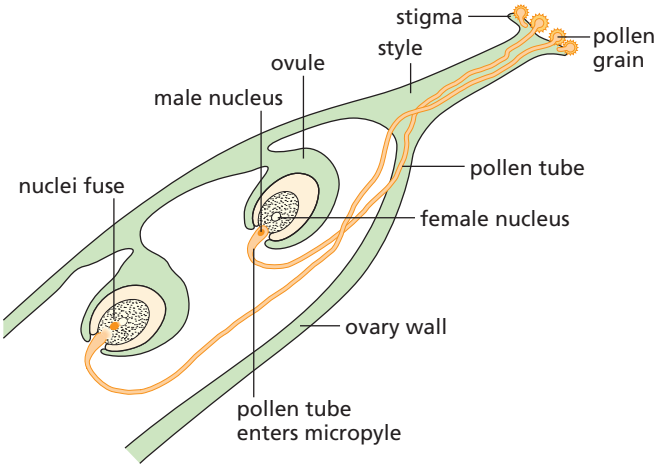


▲ **Figure 16.37** Fertilisation. The male and female gametes fuse to form a zygote, which grows into a new individual

The pollen grain absorbs liquid from the stigma and a microscopic pollen tube grows out of the grain. This tube grows down the style and into the ovary, where it enters a small hole, the micropyle, in an ovule (Figure 16.38). The nucleus of the pollen grain travels down the pollen tube and enters the ovule. Here it combines with the nucleus of the egg cell. Each ovule in an ovary needs to be fertilised by a separate pollen grain.

Although pollination must occur before the ovule can be fertilised, pollination does not always result in fertilisation. A bee may visit many flowers on a Bramley apple tree, transferring pollen from

one flower to another. The Bramley, however, is *self-sterile*. Pollination with its own pollen will not result in fertilisation. Pollination with pollen from a different variety of apple tree, for example, a Worcester, can result in successful fertilisation and fruit formation. After fertilisation, an ovule becomes a seed, the ovary forms the fruit.



▲ **Figure 16.38** Diagram of fertilisation showing pollen tube

Practical work

Safety

- Eye protection must be worn.

3 The growth of pollen tubes

- Use a solution containing sucrose and sodium borate. This has been prepared for you from 15g sucrose and 0.1g sodium borate in 100cm^3 water.
- Put a drop of this solution on a cavity slide and scatter some pollen grains on the drop. This can be done by scraping a ripe anther (which has opened to expose the pollen) with a mounted needle, or by touching the anther on the liquid drop.
- Cover the drop with a cover-slip and examine the slide under the microscope at 15 minute intervals. In some cases, pollen tubes may be seen growing from the grains.
- Suitable plants include lily, narcissus (Nargis), tulip, Indian Blanket Flower, bluebell, lupin, wallflower, sweet pea or deadnettle, but a 15% sucrose solution may not be equally suitable for all of them. You may need to experiment with solutions ranging from 5–20%.

Practical work question

4 Suggest why different species of flowers produce different concentrations of sugar on their stigmas.

Adaptation

Insect-pollinated flowers are adapted in a range of ways to their method of pollination. The term adaptation suggests that the structure and physiology of a flower have changed in ways that improve the chances of successful pollination by insects. This process is called evolution.

Most insect-pollinated flowers have brightly coloured petals and scent, which attract a variety of insects. Some flowers produce nectar, which is also attractive to many insects. Scientists think that the dark lines (called honey guides) on petals help direct the insects to the nectar source, bringing them into contact with the stamens and stigma in the process.

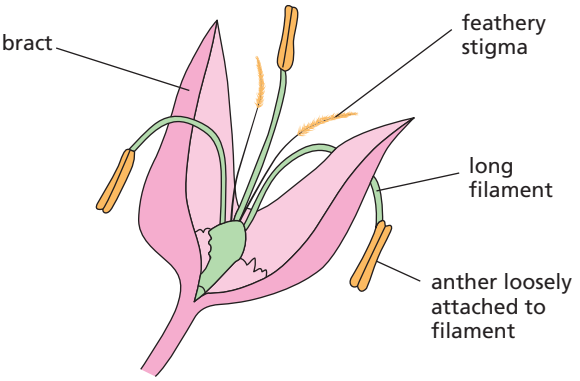
Many flowers have modifications that adapt them to pollination by only one type or species of insect. Flowers like honeysuckle, with narrow, deep petal tubes, are likely to be pollinated only by moths or butterflies. These insects have long mouthparts, acting like straws, tongues which can reach down the tube to the nectar.

Tube-like flowers like foxgloves need to be visited by larger insects to effect pollination. The petal tube is often lined with dense hairs, which stop small insects that would take the nectar without pollinating the flower. A large bumble-bee, however, pushing into the petal tube, is forced to rub against the anthers and stigma.

Many tropical and subtropical flowers are adapted to pollination by birds, such as hummingbirds and sunbirds (Figure 16.39), or even by mammals like bats and mice.

▲ **Figure 16.39** A sunbird feeding from a tube-shaped flower

Wind-pollinated flowers are adapted to their method of pollination by producing large quantities of light pollen. They also have anthers and stigmas that hang outside the flower (Figures 16.35 and 16.40). Many grasses have anthers that are not rigidly attached to the filaments and can be shaken by the wind. The stigmas of grasses are feathery, giving a large surface area, and act as a net that traps passing pollen grains.



▲ **Figure 16.40** Wind-pollinated grass flower

Table 16.5 compares the features of wind- and insect-pollinated flowers.

▼ **Table 16.5** Features of wind- and insect-pollinated flowers

Feature	Insect-pollinated	Wind-pollinated
petals	present – often large, coloured and scented, with guidelines to guide insects into the flower	absent, or small and green
nectar	produced by nectaries to attract insects	absent
stamen	present inside the flower	long filaments allowing the anthers to hang freely outside the flower so the pollen is exposed to the wind
stigmas	small surface area; inside the flower	large and feathery; hanging outside the flower to catch pollen carried by the wind
pollen	smaller amounts; grains are often round and sticky or covered in spikes to attach to the furry bodies of insects	larger amounts of smooth and light pollen grains, which are easily carried by the wind
bracts (modified leaves)	absent	sometimes present

Test yourself

8 Working from outside to inside, list the parts of a bisexual flower (one with male and female parts).

9 State what features of flowers might attract insects.

10 State which part of a flower becomes
- **a** the seed
- **b** the fruit.

11 Put the following events in the correct order for pollination in a lupin plant:
- **A** Bee gets dusted with pollen.
- **B** Pollen is deposited on stigma.
- **C** Bee visits older flower.
- **D** Bee visits young flower.
- **E** Anthers split open.

Fruit and seed formation

After the pollen and the egg nuclei have fused, the egg cell divides many times and produces a miniature plant called an **embryo**. This consists of a tiny root (radicle) and shoot (plumule) with two special leaves called **cotyledons**. In dicot plants (see 'Features of organisms' in Chapter 2), food made in the leaves of the parent plant is carried in the phloem to the cotyledons.

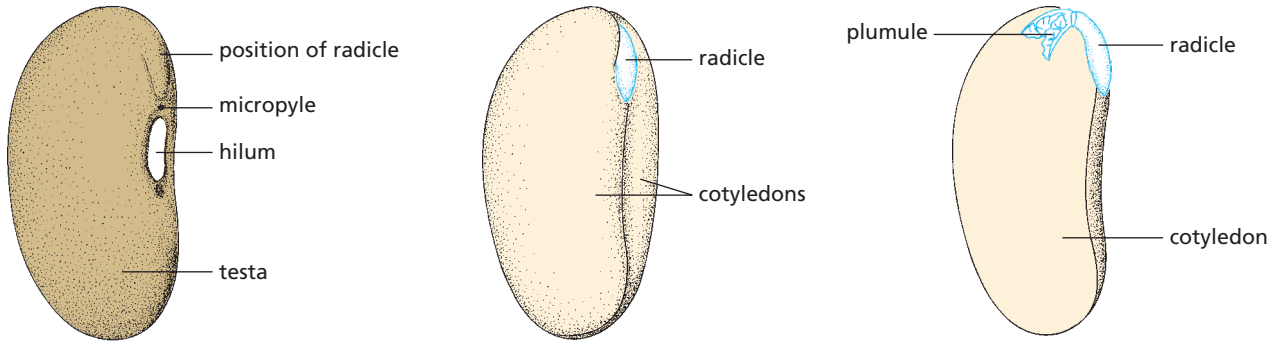
The cotyledons eventually grow so large with this stored food that they enclose the embryo completely (see Figure 16.42). In monocot plants (see 'Features of organisms' in Chapter 2), the food store is laid down in a special tissue called endosperm, which is outside the cotyledons. In both cases the outer wall of the ovule becomes thicker and harder, and forms the seed coat or **testa**.

(a)

(b)

(c)

▲ **Figure 16.41** Tomato; fruit formation
(a) Tomato flowers – the petals of the older flowers are shrivelling
(b) After fertilisation – the petals have dropped and the ovary is growing
(c) Ripe fruit – the ovary has grown and ripened. The green sepals remain and the dried stigma is still attached.



(a) external appearance **(b)** testa removed **(c)** one cotyledon removed

▲ **Figure 16.42** A French bean seed

As the seeds grow, the ovary also becomes much larger and the petals and stamens shrivel and fall off (Figure 16.41(b)). The ovary is now called a **fruit** (Figure 16.41(c)). It is not necessarily edible – the lupin ovary forms a dry pod (Figure 16.43).

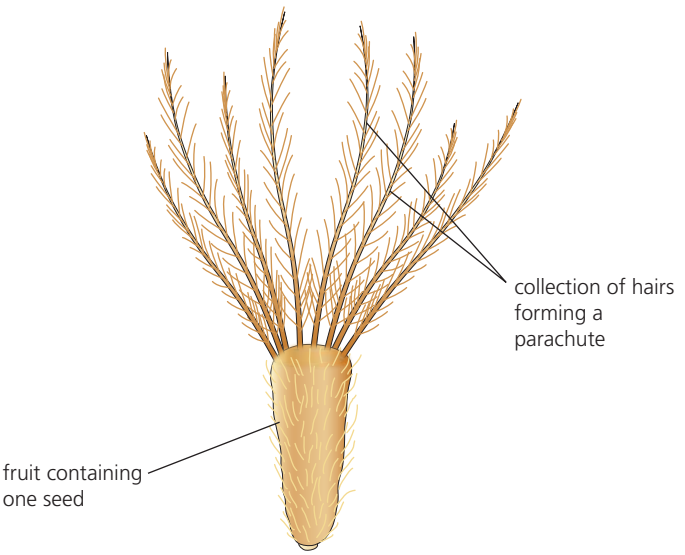
▲ **Figure 16.43** Lupin flower after fertilisation. The ovary (still with the style and stigma attached) has grown much larger than the flower and the petals have shrivelled

Fruit and seed dispersal

In many plants, the fruits or seeds are adapted to enable their distribution away from the parent plant. This is a means of colonising new areas. It also helps to reduce overcrowding and competition between members of the same species for light, air, water and mineral ions.

Wind dispersal

1 Parachute fruits and seeds: feathery hairs projecting from a fruit or seed increase its surface area so much that it tends to be carried by slight air currents. In some species of plant, such as Tridax, shown in Figure 16.44, the collection of hairs on the fruit is formed from the sepals of the flower.



▲ **Figure 16.44** Tridax fruit, with a collection of hairs forming a parachute

2 Winged fruits and seeds: fruits of the Combretum (red bushwillow) plant (Figure 16.45) have extensions of the ovary wall which make a wing-like structure. The extra surface area of these wings gives increased air resistance, allowing the fruit to be carried by the wind away from the parent plant.

▲ **Figure 16.45** Winged fruit of the red bushwillow plant

Animal dispersal

1 Hooked fruits, dispersed by mammals: the plant Acanthospermum, found in Central and South America, produces a hooked fruit (Figure 16.46). The hooks develop on the ovary wall and can catch the fur of passing mammals. At some distance from the parent plant they fall off or are brushed off by the animal.

▲ **Figure 16.46** Hooked fruit of Acanthospermum

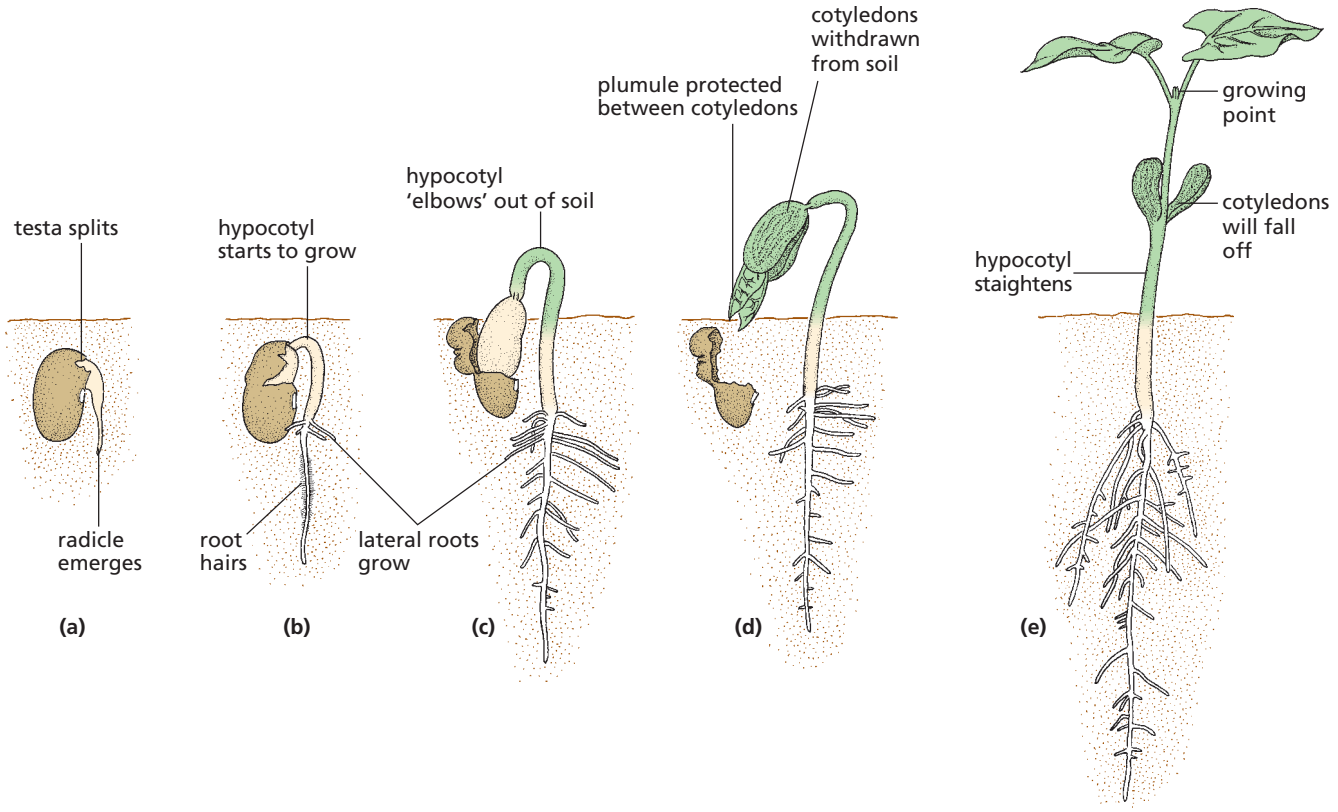
2 Succulent fruits: these are fruits with flesh that can be eaten. They often have a brightly coloured skin to attract animals. One example is the tomato, as shown in Figure 16.41(c). The seeds inside the fruit have resistant coats, allowing them to pass through the animal's digestive system, to be dropped with the faeces some distance away from the parent plant. Fruits such as the mango may be carried away from the parent plant by animals such as rats. The flesh will be eaten and the seed discarded.

Germination

Germination is the process of development of a plant from a seed.

The stages of germination of a French bean are shown in Figure 16.47.

A fresh seed contains only 5–20% water, compared with 80–90% in mature plant tissues. When in the soil, some seeds will absorb water and swell up, but will not start to germinate until other conditions are suitable.



▲ **Figure 16.47** Germination of a French bean

The radicle (future shoot of the plant) grows first and bursts through the testa (the seed coat – Figure 16.47(a)). The radicle continues to grow down into the soil, pushing its way between soil particles and small stones. Its tip is protected by the root cap (see 'Water uptake' in Chapter 7). Branches, called lateral roots, grow out from the side of the main root and help to anchor it firmly in the soil. Microscopic root hairs (see Chapter 1) grow out from the roots. They make close contact with the soil particles and absorb water from the spaces between them.

In the French bean a region of the embryo's stem called the hypocotyl, just above the radicle (Figure 16.47(b)), now starts to elongate. The radicle has firmly anchored in the soil, so the rapidly growing hypocotyl moves upwards through the soil, pulling the cotyledons with it (Figure 16.47(c)). The plumule (the shoot of the seed) is well protected from damage while it is being pulled through the soil, because it is in between the cotyledons (Figure 16.47(d)).

Once the cotyledons are above the soil, the hypocotyl straightens up and the leaves of the plumule open out (Figure 16.47(e)). Up to this point, all the food needed for making new cells and producing energy has come from the cotyledons.

The main type of food stored in the cotyledons is starch. Before this can be used by the growing shoot and root, the starch must be turned into soluble sugar. In this form, it can be transported by the phloem cells. The change from starch to sugar in the cotyledons is controlled by enzymes, which become active as soon as the seed starts to germinate. The cotyledons get smaller as their food reserve is used up, and they fall off soon after they have been brought above the soil.

By now the plumule leaves have grown much larger and have turned green. They absorb sunlight and make their own food by photosynthesis (Chapter 6). Between the plumule leaves is a growing point, which continues the upward growth of the stem and the production of new leaves. The embryo has now become an independent plant, absorbing water and mineral ions from the soil, carbon dioxide from the air and making food in its leaves.

The importance of temperature, water and oxygen in germination

Importance of a suitable temperature

In Chapter 5 it was explained that a rise in temperature speeds up most chemical reactions, including those taking place in living organisms. So, germination happens more rapidly at high temperatures, up to about 40 °C. Above 45 °C, the enzymes in the cells are denatured and the seedlings would be killed. Below certain temperatures (e.g. 0–4 °C) germination may not start at all in some seeds. However, the range of temperatures at which seeds of different species will germinate does vary.

Importance of water

When first dispersed, most seeds contain very little water. In this dehydrated state their metabolism is very slow, and their food reserves are not used up. Dry seeds are also protected from extreme temperatures and dryness. Before the metabolic changes needed for germination can take place, seeds must absorb water.

First, water is absorbed through a tiny hole in the seed coat called the micropyle, and then through the whole seed coat. Once the radicle has appeared, it will absorb water from the soil, especially through the root hairs. The water that reaches the embryo and cotyledons is used to

- activate the enzymes in the seed
- help the conversion of stored starch to sugar, and proteins to amino acids
- transport the sugar in solution from the cotyledons to the growing regions
- expand the vacuoles of new cells, causing the root and shoot to grow and the leaves to expand
- maintain the turgor (Chapter 3) of the cells. This keeps the shoot upright and the leaves expanded
- provide the water needed for photosynthesis when the plumule and young leaves are above ground
- transport mineral ions from the soil to the shoot.

Importance of oxygen

In some seeds the seed coat is not very permeable to oxygen, which suggests that the early stages of germination are anaerobic (Chapter 10). When soaked or split open, the seed coat allows oxygen to enter. The oxygen is used in aerobic respiration. This provides the energy for the chemical changes involved in activating the food reserves and making the new cytoplasm and cell walls of the growing seedling.

Practical work

Safety

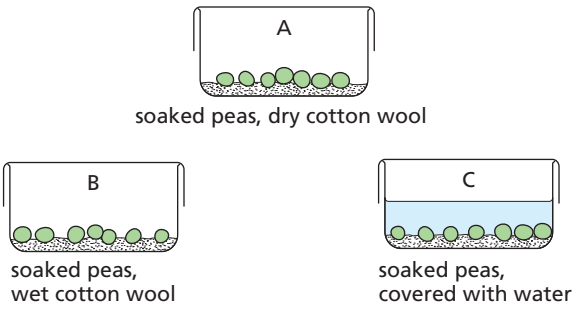
- Eye protection must be worn.

Experiments on the conditions for germination

The environmental conditions that can affect germination are temperature, light intensity and the availability of water and oxygen.

4 The need for water

- Label three containers A, B and C and put dry cotton wool in the bottom of each.
- Place equal numbers of soaked seeds in all three.
- Keep the cotton wool in container A dry; add water to B to make the cotton wool moist; add water to C until all the seeds are completely covered (Figure 16.48).
- Put lids on the containers and leave them all at room temperature for a week.



▲ **Figure 16.48** Experiment to show the need for water in germination

Result

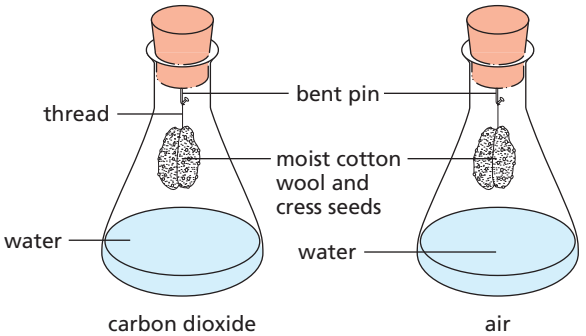
The seeds in B will germinate normally. Those in A will not germinate. The seeds in C may have started to germinate but will probably not be as developed as those in B and may have died and started to decay.

Interpretation

Although water is necessary for germination, too much of it may prevent germination by cutting down the oxygen supply to the seed.

5 The need for oxygen

- Set up the experiment as shown in Figure 16.49.
- If the moist cotton wool is rolled in some cress seeds, they will stick to it. The stoppers must make an airtight seal in the flask.
- Fill flask A with carbon dioxide. This can be done by generating CO_2 using dilute (≤ 1M) hydrochloric acid and calcium carbonate chips in a side-arm flask with a stopper. Attach a rubber tube to the side arm and place it in the bottom of the flask being used in the experiment. The CO_2, being more dense than air, will fill the flask, forcing any air out. So, the cress seeds in flask A are deprived of oxygen. Flask B is the control (see 'Aerobic respiration' in Chapter 10). This is to show that germination can take place in these experimental conditions provided oxygen is present.
- Leave the flasks for a week at room temperature.



▲ **Figure 16.49** Experiment to show the need for oxygen in germination

Result

The seeds in flask B will germinate but there will be little or no germination in flask A.

Interpretation

The main difference between flasks A and B is that A lacks oxygen. Since the seeds in this flask have not germinated, this suggests that oxygen is needed for germination.

To show that the carbon dioxide in flask A had not killed the seeds, the cotton wool can be swapped from A to B. The seeds from A will now germinate.

6 Temperature and germination

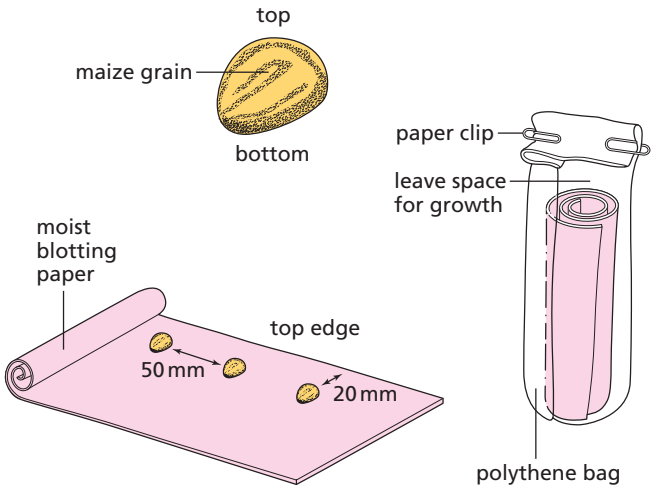
- Soak some maize grains for a day and then roll them up in three strips of moist blotting paper as shown in Figure 16.50.
- Put the rolls into plastic bags. Place one in a refrigerator (about 4 °C), leave one upright at a temperature of about 20 °C and put the third in a warm place or, better, in an incubator set to 30 °C.
- Because the seeds in the refrigerator will be in darkness, the other seeds must also be enclosed in a box or a cupboard to prevent them getting any light. Otherwise, you could argue that it was lack of light rather than low temperature that affected germination.
- After a week, examine the seedlings and measure the length of the roots and shoots.

Result

The seedlings kept at 30 °C will be more developed than those at 20 °C. The grains in the refrigerator may not have started to germinate at all.

Interpretation

Seeds will not germinate below a certain temperature. The higher the temperature, the faster the germination, at least up to 35–40 °C.



▲ **Figure 16.50** Experiment to show the effect of temperature on germination. Roll the seeds in moist blotting paper and stand the rolls upright in plastic bags

Controlling the variables

These experiments on germination show one of the problems of designing biological experiments. You have to decide what conditions (the variables) could affect the results and then try to change only one condition at a time. The dangers are that: (1) some of the variables might not be controllable, (2) controlling some of the variables might also affect the condition you want to investigate, and (3) there might be a number of important variables you have not thought of.

1 In your germination experiments, you were unable to control the quality of the seeds, but had to assume that the differences between them would be small. If some of the seeds were dead or diseased they would not germinate in any conditions and this could alter the results. This is one reason for using as large a sample as possible in the experiments.

2 You had to make sure that, when temperature was the variable, blocking the light from the seeds in the refrigerator was not an extra variable. This was done by putting all the seeds in darkness.

3 A variable you might not have considered could be the way the seeds were handled. Some seeds can be stimulated to germinate more successfully by scratching or chipping the seed coat.

Practical work questions

5 For experiment 4, state two factors which need to be kept the same to make the experiment a fair test.

6 For experiment 5, explain how you know that carbon dioxide did not kill the seeds, but just stopped them germinating.

7 For experiment 6, describe how you could obtain data to calculate the percentage germination rate of seeds for a range of temperatures.

8 Identify one safety point for each of the following experiments
- **a** growth of pollen tubes (see page 261)
- **b** the need for water
- **c** the need for oxygen.

Test yourself

12 Suggest how a growing seedling might use the food stored in its cotyledons.

13 Suggest at what stage of development a seedling is able to stop depending on the cotyledons for its food.

14 **a** Describe the natural conditions in the soil that would be most favourable for germination.
b Suggest how a gardener could try to create these conditions.

Sexual reproduction in humans

FOCUS POINTS

- ★ What are the parts of the male and female reproductive systems and what are their functions?
- ★ What are the features of sperm and egg cells that help reproduction?
- ★ What are the differences between male and female gametes?
- ★ What happens when a zygote develops into an embryo?
- ★ Why are the umbilical cord, placenta, amniotic sac and amniotic fluid important for the development of the fetus?
- ★ What is the function of the placenta and umbilical cord?
- ★ What can happen when some viruses and toxins pass across the placenta?

Key definitions

Fertilisation is the fusion of the nuclei from a male gamete (sperm) and a female gamete (egg cell).

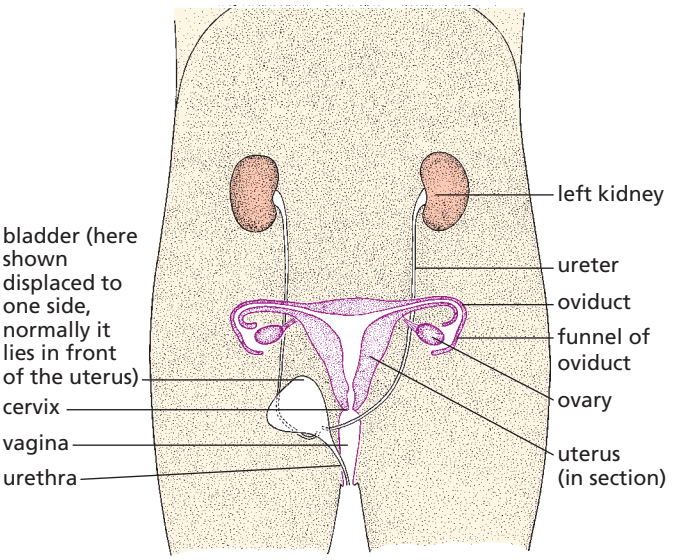
Reproduction is the process of producing new individuals. In human reproduction, the two sexes, male and female, each produce special types of reproductive cells called gametes. The male gametes are the sperm and the female gametes are the egg cells (see Figure 16.56).

The human reproductive system

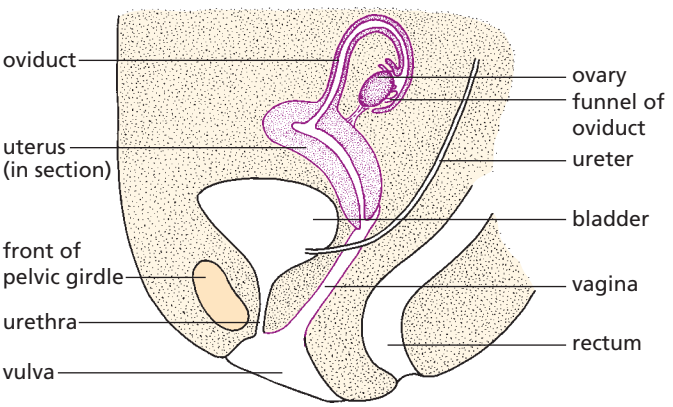
Female

Table 16.6 summarises the functions of parts of the female reproductive system. The eggs are produced from the female reproductive organs called **ovaries**. These are two whitish oval bodies, 3–4 cm long. They lie in the lower half of the abdomen, one on each side of the uterus (Figure 16.51 and 16.52). Close to each ovary is the expanded, funnel-shaped opening of the **oviduct**, the tube down which the eggs pass when released from the ovary. The oviduct is sometimes called the **fallopian tube**.

The oviducts are narrow tubes that open into a wider tube, the uterus or womb, lower down in the abdomen. When there is no embryo developing in it, the uterus is only about 80 mm long. It leads to the outside through a muscular tube, the **vagina**. The **cervix** is a ring of muscle closing the lower end of the uterus where it joins the vagina. The urethra, from the bladder, opens into the vulva just in front of the vagina.



▲ **Figure 16.51** The female reproductive organs; front view



▲ **Figure 16.52** The female reproductive organs; side view

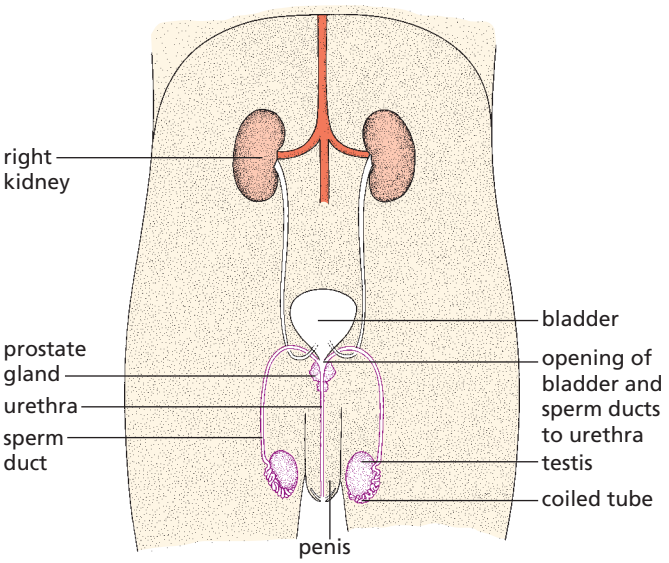
▼ **Table 16.6** Functions of parts of the female reproductive system

Part	Function
cervix	a ring of muscle separating the vagina from the uterus
ovary	female gonad, contains follicles in which eggs are produced
oviduct	carries an egg cell to the uterus, with propulsion provided by tiny cilia in the wall; also, the site of fertilisation
uterus	where the fetus develops
vagina	receives the male penis during sexual intercourse; sperm are deposited here

Male

Table 16.7 summarises the functions of parts of the male reproductive system. Sperm are produced in the male reproductive organs (Figures 16.53 and 16.54), called the **testes** (singular = **testis**). These lie outside the abdominal cavity in a special sac called the **scrotum**. In this position they are kept at a temperature slightly below the rest of the body. This is the best temperature for sperm production.

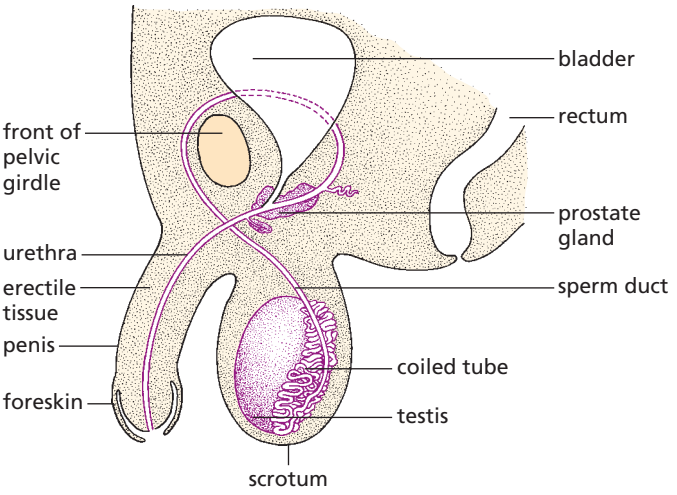
The testes consist of a mass of sperm-producing tubes (Figure 16.54). These tubes join to form ducts leading to a coiled tube about 6 metres long on the outside of each testis. This tube leads into a muscular **sperm duct**.



▲ **Figure 16.53** The male reproductive organs; front view

The two sperm ducts, one from each testis, open into the top of the urethra just after it leaves the bladder. The sperm ducts enter the **prostate gland**, which surrounds the urethra at this point.

The urethra passes through the **penis** and may carry either urine or sperm at different times. The penis consists of connective tissue with many blood spaces in it. This is called erectile tissue.

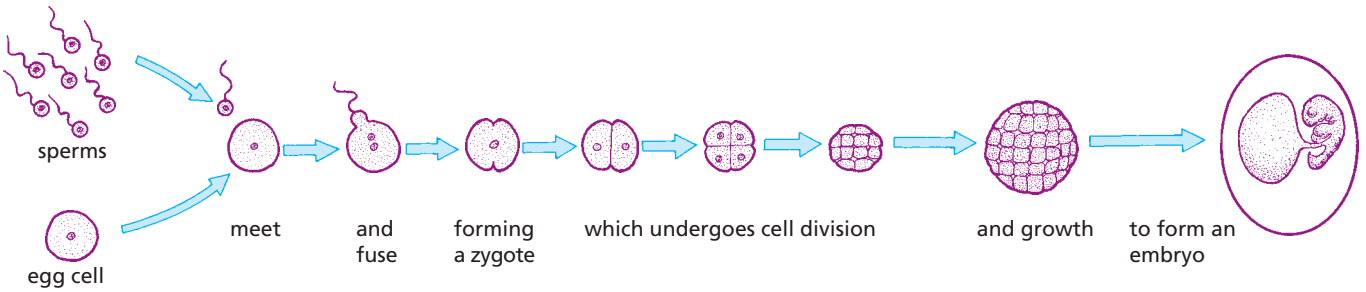


▲ **Figure 16.54** The male reproductive organs; side view

▼ **Table 16.7** Functions of parts of the male reproductive system

Part	Function
penis	can become firm to insert into the vagina of the female during sexual intercourse in order to transfer sperm
prostate gland	adds fluid and nutrients to sperm to form semen
scrotum	a sac that holds the testes outside the body, keeping them cooler than body temperature
sperm duct	muscular tube that links the testis to the urethra to allow the passage of semen containing sperm
testis	male gonad that produces sperm
urethra	passes semen containing sperm through the penis; also carries urine from the bladder

To produce a new individual, a sperm needs to reach an egg cell and fuse with it. The sperm nucleus then passes into the egg cell and the two nuclei also fuse. This is fertilisation. The cell formed after the fertilisation of an egg cell by a sperm is called a zygote. A zygote will grow by cell division to produce first an embryo (Figure 16.55) and then a fully formed animal.



▲ **Figure 16.55** Fertilisation and development

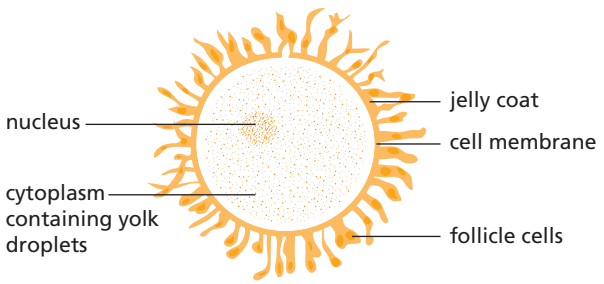
In humans, the male produces millions of sperm, while the female produces a smaller number of eggs (usually one a month for about 40 years). Usually only one egg is fertilised at a time; two eggs being fertilised at the same time produces (non-identical) twins.

To bring the sperm close enough to the eggs for fertilisation to take place, there is an act of mating. In mammals this act results in sperm from the male animal being injected by the penis into the female. The sperm swim inside the female's reproductive system and fertilise any eggs that are present. The zygote then grows into an embryo inside the body of the female.

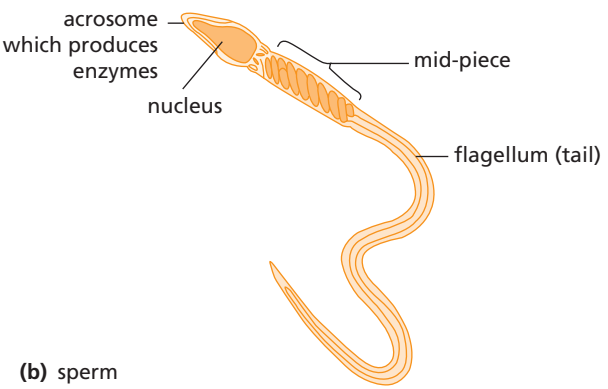
Comparing male and female gametes

Figure 16.56(b) shows a sperm cell in detail. Sperm are much smaller than eggs and are produced in much larger numbers (over 300 million in a single ejaculation). The tip of the cell carries an acrosome. This secretes enzymes which can digest the jelly coat of an egg cell so the sperm nucleus can fuse with the egg nucleus. The cytoplasm of the mid-piece of the sperm contains many mitochondria. They carry out respiration, providing energy to make the **flagellum** (tail) move and propel the sperm forward.

The egg cell (see Figure 16.56(a)) is much larger than a sperm cell. Only one egg is released each month while the woman is fertile. It is surrounded by a jelly coat, which protects the contents of the cell and prevents more than one sperm from entering and fertilising the egg. The egg cell contains a large amount of cytoplasm, which is rich in lipids and proteins. The lipids act as energy stores. Proteins are available for growth if the egg is fertilised.



(a) egg cell



(b) sperm

▲ **Figure 16.56** Human gametes

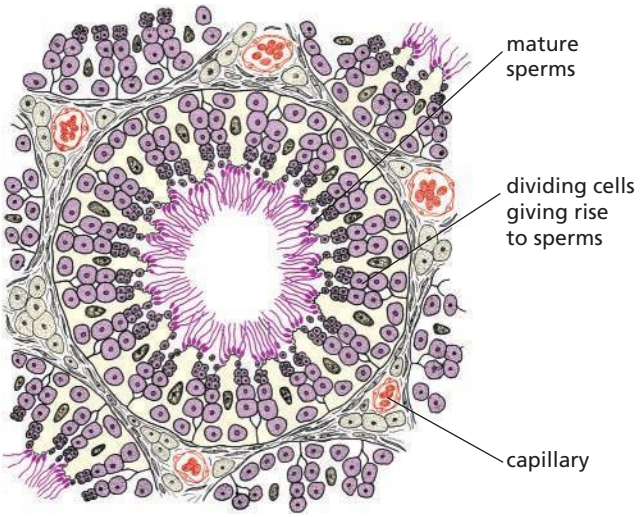
Going further

Production of gametes

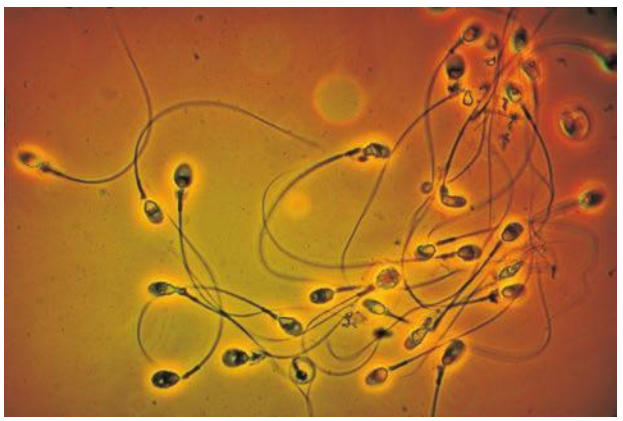
Sperm production

The lining of the sperm-producing tubules in the testis consists of rapidly dividing cells (Figure 16.57). After a series of cell divisions, the cells grow long tails called flagella (singular: flagellum) and become sperm (Figure 16.58), which pass into the coiled tube.

During copulation, the coiled tube and sperm ducts contract and force sperm out through the urethra. The prostate gland adds fluid to the sperm. This fluid plus the sperm it contains is called semen, and the ejection of sperm through the penis is called ejaculation.



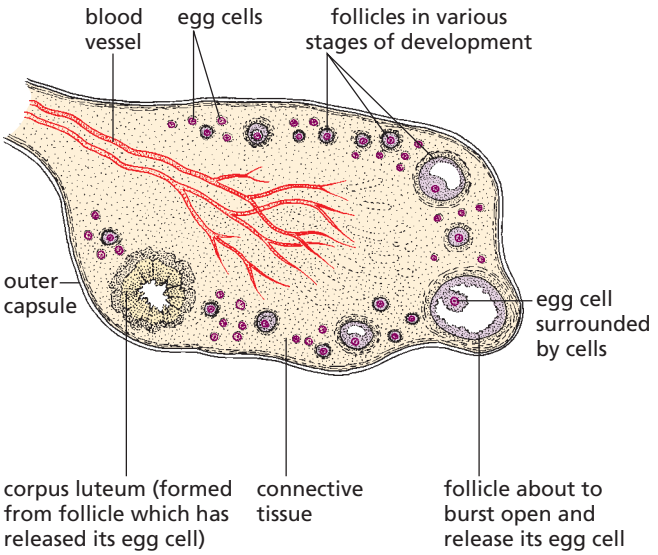
▲ **Figure 16.57** Section through sperm-producing tubules



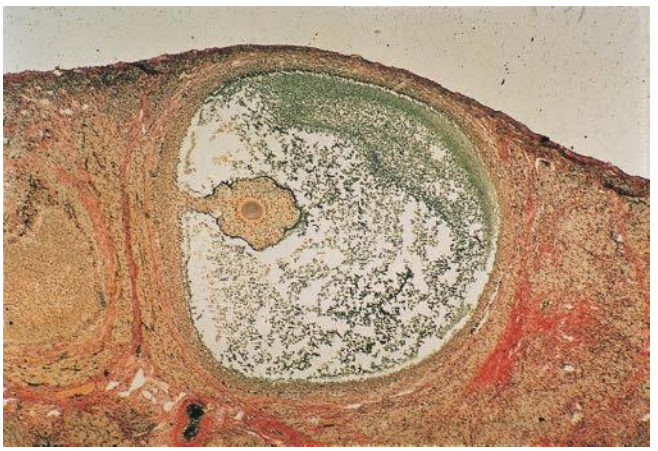
▲ **Figure 16.58** Human sperm (×800). The head of the sperm has a slightly different appearance when seen in 'side' view or in 'top' view

Ovulation

The egg cells (ova) are present in the ovary from the time of birth. No more are formed during the female's lifetime, but between the ages of 10 and 14 some of the egg cells start to mature and are released one at a time about every 4 weeks from alternate ovaries. As each egg cell matures, the cells around it divide rapidly and produce a fluid-filled sac. This sac is called a follicle (Figure 16.59) and, when mature, it forms a small bump on the surface of the ovary like a small blister (Figure 16.60). Finally, the follicle bursts and releases the egg cell with its coating of cells into the funnel of the oviduct. This is called ovulation. From here, the egg cell is wafted down the oviduct by the action of cilia (see Chapter 1) in the lining of the tube.



▲ **Figure 16.59** Section through an ovary



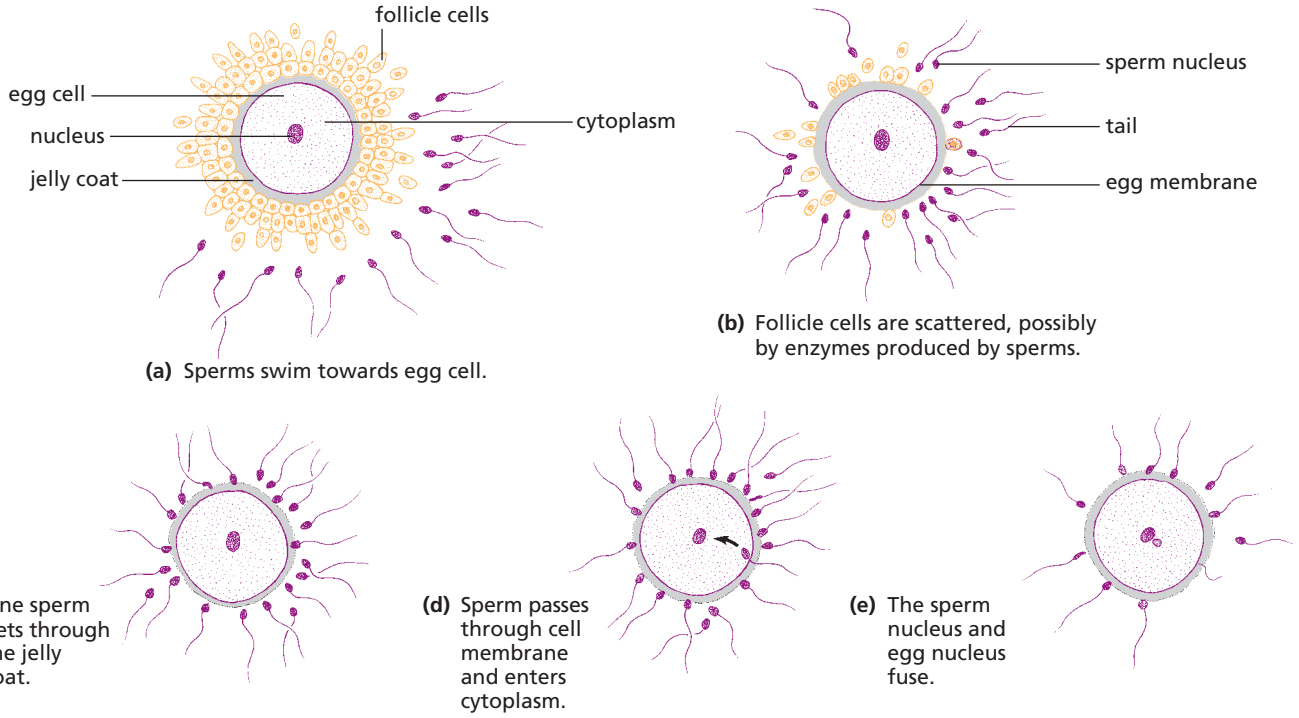
▲ **Figure 16.60** Mature follicle as seen in a section through part of an ovary (×30). The egg cell is surrounded by follicle cells. These produce the fluid that occupies much of the space in the follicle

Fertilisation

The sperm swim through the cervix and into the uterus by wriggling movements of their tails. They pass through the uterus and enter the oviduct. If there is an egg cell in the oviduct, one of the sperm may bump into it and stick to its surface. The acrosome at the head of the sperm secretes enzymes, which digest a channel through the jelly coat and part of the egg membrane. The sperm then enters the cytoplasm of the egg cell and the male nucleus of the sperm fuses with the female nucleus. This is the moment of fertilisation and is shown in more detail in Figure 16.61. Although a single ejaculation may contain over three hundred million sperm, only a few hundred will reach the oviduct and only one will fertilise the egg cell. The function of the others is not fully understood.

The released egg cell can survive for about 24 hours; the sperm might be able to fertilise an egg cell for about 2 or 3 days. So, there is only a short period of about 4 days each month when fertilisation might occur.

The fertilised egg has 23 chromosomes from the mother and 23 from the father, bringing its chromosome number to 46 (the same as other human body cells). It is called a zygote.



(a) Sperms swim towards egg cell.

(b) Follicle cells are scattered, possibly by enzymes produced by sperms.

(c) One sperm gets through the jelly coat.

(d) Sperm passes through cell membrane and enters cytoplasm.

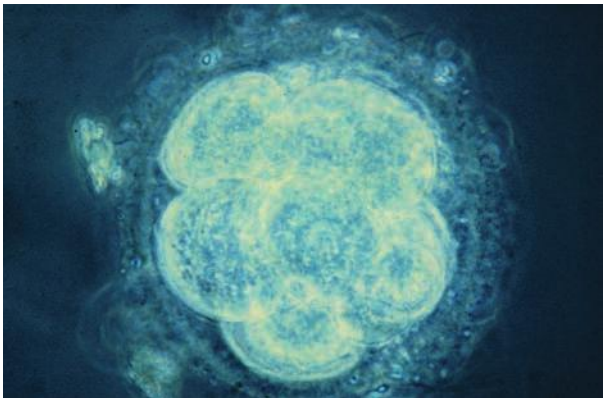
(e) The sperm nucleus and egg nucleus fuse.

▲ **Figure 16.61** Fertilisation of an egg cell

Pregnancy and development

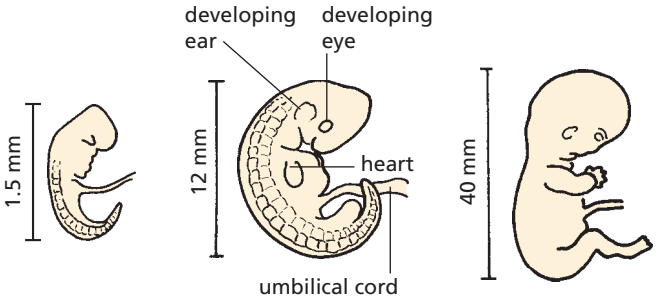
The fertilised egg cell (zygote) is protected from other sperm by changes to the jelly coat, which now acts as a barrier. The zygote first divides into two cells. Each of these divides again, so producing four cells. The cells continue to divide in this way to produce a solid ball of cells (Figure 16.62), an early stage in the development of the embryo. This early embryo travels down the oviduct to the uterus. Here it **implants** or sinks into the lining of the uterus (Figure 16.64(a)). The embryo continues to grow and produces new cells that form tissues and organs (Figure 16.63). After 8 weeks, when all the organs are formed, the embryo is called a fetus. One of the first organs to form is the heart, which pumps blood around the body of the embryo.

As the embryo grows, the uterus enlarges to contain it. Inside the uterus the embryo becomes enclosed in a fluid-filled sac called the **amniotic sac**, which protects it from damage and prevents unequal pressures from acting on it (Figure 16.64(b) and (c)). The fluid is called **amniotic fluid**. The oxygen and food needed to keep the embryo alive and growing are obtained from the mother's blood by means of a structure called the placenta.



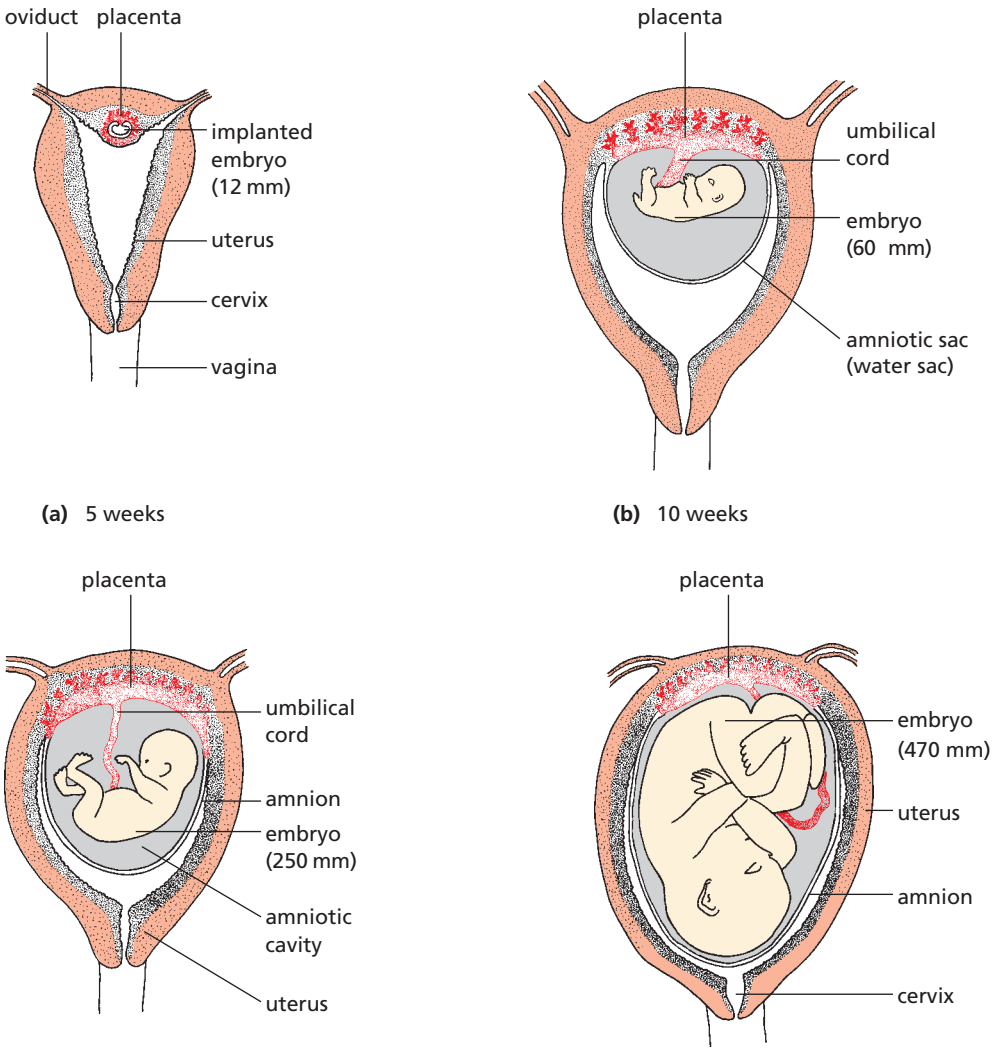
▲ **Figure 16.62** Human embryo at the eight-cell stage with five of the cells clearly visible. The embryo is surrounded by the zona pellucida

Going further



(a) after 2 weeks **(b)** about 5 weeks **(c)** 8 weeks

▲ **Figure 16.63** Human embryo: the first 8 weeks



(a) 5 weeks **(b)** 10 weeks

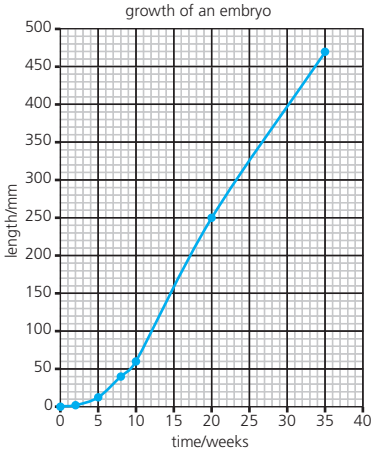
(c) 20 weeks **(d)** 35 weeks (a few weeks before birth)

▲ **Figure 16.64** Growth and development in the uterus (not to scale)

Worked example

Collect the data from Figures 16.63 and 16.64 (age and lengths of the embryos and fetuses) and put them in a table.

Use the data to plot a graph of age against length.



How to complete the task

- First, decide on suitable headings for a table: remember to write a descriptor and state the units.
- So, the first descriptor will be *time*. Its units are *weeks*.
- The second descriptor will be *length of embryo*. Its units are *mm*.
- There are seven diagrams with data, but you should also include 0 weeks and 0 mm, so you will need eight rows below the headings.
- Then transfer data from the diagrams in order of time, from smallest to largest (2 weeks to 35 weeks).
- Now you can use this organised data to plot a graph. It will be a line graph because of the nature of the data.
- Always use a sharp HB pencil and a ruler.
- Choose suitable axes. In this case, the independent variable* (which goes on the horizontal, or *x*-axis) is time.
- Choose a suitable scale. It needs to go from 0 to 35 weeks.
  Going up in 5 week or 10 week intervals would be straightforward. Plan this so you use most of your graph paper.
- Do not forget to label the axis and write the units. You can use the same as the header in the table.
- Now you need to work on the dependent variable** (going on the vertical, or *y*-axis), which is the length of the embryo. Choose a suitable scale. It needs to go from 0 to 470 mm, but choose an easy number above this to use (e.g. 500). Going up in 50 or 100 mm intervals would work. Again, plan this so you use most of your graph paper.
- Do not forget to label the axis and write the units. You can use the same as the header in the table.
- You can now plot the points. Use a dot with a circle round it or a cross.
- Finally, join the points with a smooth, unbroken line.

*The independent variable is also known as the input variable or fixed variable.

**The dependent variable is also known as the outcome or unfixed variable.

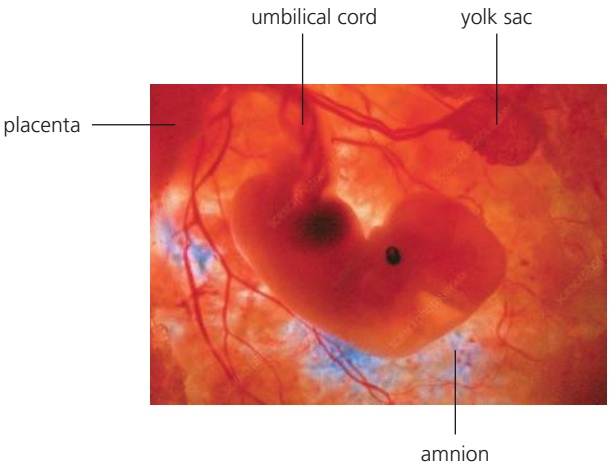
Tasks

1 a Use data from the graph to calculate the rate of growth per day
  i) between 0 and 5 weeks
  ii) between 15 and 20 weeks.
  b Calculate the percentage increase in growth rate.

Placenta

Soon after the ball of cells reaches the uterus, most of the cells form the organs of the embryo. However, some cells grow into a disc-like structure called the placenta (Figure 16.64(a)). The placenta becomes closely attached to the lining of the uterus and is attached to the embryo by a tube called the **umbilical cord** (Figure 16.64(b)). The nervous system (brain, spinal cord and sense organs) start to develop very quickly. After a few weeks, the embryo's heart has developed and is circulating blood through the umbilical cord and placenta as well as through its own tissues. Oxygen and nutrients like glucose, amino acids and ions pass across the placenta to the embryo's bloodstream through blood vessels in the umbilical cord. Carbon dioxide and urea pass from the embryo's blood to the mother's blood, also through blood vessels in the umbilical cord. Blood entering the placenta from the mother does not mix with the embryo's blood. This is important because the mother and embryo may have different blood groups.

Figure 16.65 shows the human embryo at 7 weeks surrounded by the amniotic sac and placenta.



▲ **Figure 16.65** Human embryo, 7 weeks (×1.5). The embryo is surrounded by the amniotic sac. Its limbs, eye and ear-hole are clearly visible. The amniotic sac is surrounded by the placenta; the fluffy-looking structures are the placental villi, which are embedded in the lining of the uterus. The umbilical cord connects the embryo to the placenta

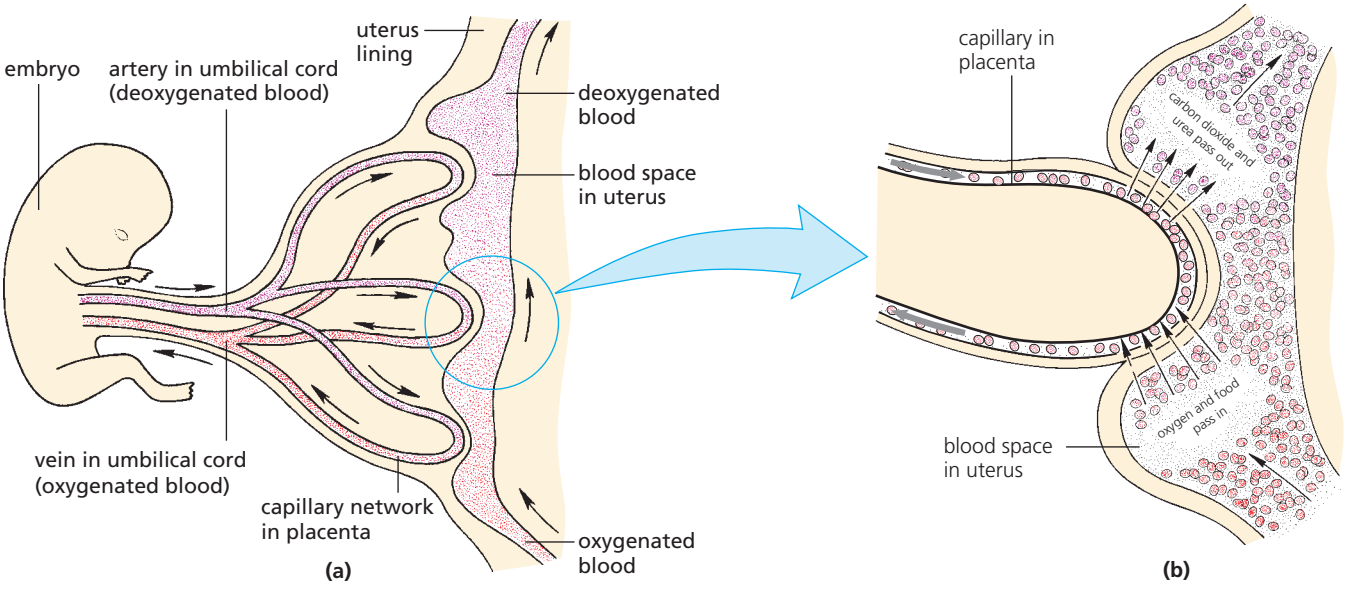
Functions of the placenta and umbilical cord

The blood vessels in the placenta are very close to the blood vessels in the uterus so that oxygen, glucose, amino acids and ions can pass from the mother's blood to the embryo's blood by diffusion (Figure 16.66(a)). So, the blood flowing in the umbilical vein from the placenta carries food and oxygen. These are used by the living, growing tissues of the embryo. In a similar way, the carbon dioxide and urea in the embryo's blood escape from the vessels in the placenta and are carried away by the mother's blood in the uterus (Figure 16.66(b)). In this way the embryo gets rid of its excretory products.

There is no direct communication between the mother's blood system and that of the embryo. The exchange of substances takes place across the thin walls of the blood vessels. In this way, the mother's blood pressure cannot damage the delicate vessels of the embryo and it is possible for the placenta to select the substances allowed to pass into the embryo's blood.

The placenta can prevent some toxins (harmful substances) in the mother's blood from reaching the embryo. It cannot prevent all of them, however: alcohol and nicotine can pass to the developing fetus. If the mother is a drug addict, the baby can be born addicted to the drug.

Some viruses like the rubella virus and HIV can pass across the placenta. Rubella (German measles), although a mild infection for the mother, can infect the fetus and results in major health problems. These include deafness, congenital heart disease, diabetes and mental retardation. HIV is potentially fatal.



▲ **Figure 16.66** The exchange of substances between the blood of the embryo and the mother

Test yourself

15 Describe how sperm differ from egg cells in their structure (see Figure 16.56).
16 List the structures through which the sperm must pass, from the time they are produced in the testis to when they leave the urethra.
17 Identify what structures are shown in Figure 16.54 but are not shown in Figure 16.53.
18 State how a zygote differs from most other cells in the body.
19 List, in the correct order, the parts of the female reproductive system through which sperm must pass before reaching and fertilising an egg cell.

Sexual hormones in humans

FOCUS POINTS

- ★ What are the roles of testosterone and oestrogen during puberty?
- ★ What happens during the menstrual cycle?
- ★ What are the roles of follicle-stimulating hormone (FSH), luteinising hormone (LH), oestrogen and progesterone?

Puberty and the menstrual cycle

Puberty

Although the ovaries of a young girl contain all the eggs she will ever produce, they do not start to be released until she reaches the age of about 10–14 years. This stage in her life is known as puberty.

At about the same time as the first ovulation, the ovary also releases female sex hormones into the bloodstream. These hormones are called oestrogens and when they circulate around the body they cause the development of secondary sexual characteristics. In a girl these are the increased growth of the breasts, a widening of the hips and the growth of hair in the pubic region and in the armpits. There is also an increase in the size of the uterus and vagina. Once all these changes are complete, the girl is capable of having a baby.

Puberty in boys occurs at about the same age as in girls. The testes start to produce sperm for the first time. They also release a hormone called testosterone into the bloodstream. The male secondary sexual characteristics, which begin to appear at puberty, are enlargement of the testes and penis, deepening of the voice, growth of hair in the pubic region, armpits, chest and, later, the face. In both sexes there is a rapid increase in the rate of growth during puberty.

In addition to the physical changes at puberty, there are emotional and psychological changes linked with the change from being a child to becoming an adult. Most people adjust to these changes smoothly and without problems. Sometimes, however, a conflict occurs between having the status of a child and the feelings of an adult.

The menstrual cycle

The ovaries release an egg cell about every 4 weeks. In preparation for this the lining of the uterus wall thickens. This is to enable an embryo to embed itself if the released egg cell is fertilised. If no embryo implants, the uterus lining breaks down. The cells, along with blood, are passed out of the vagina. This is called a **menstrual period**. The appearance of the first menstrual period is one of the signs of puberty in girls. After menstruation, the uterus lining starts to re-form and another egg cell starts to mature.

Hormones and the menstrual cycle

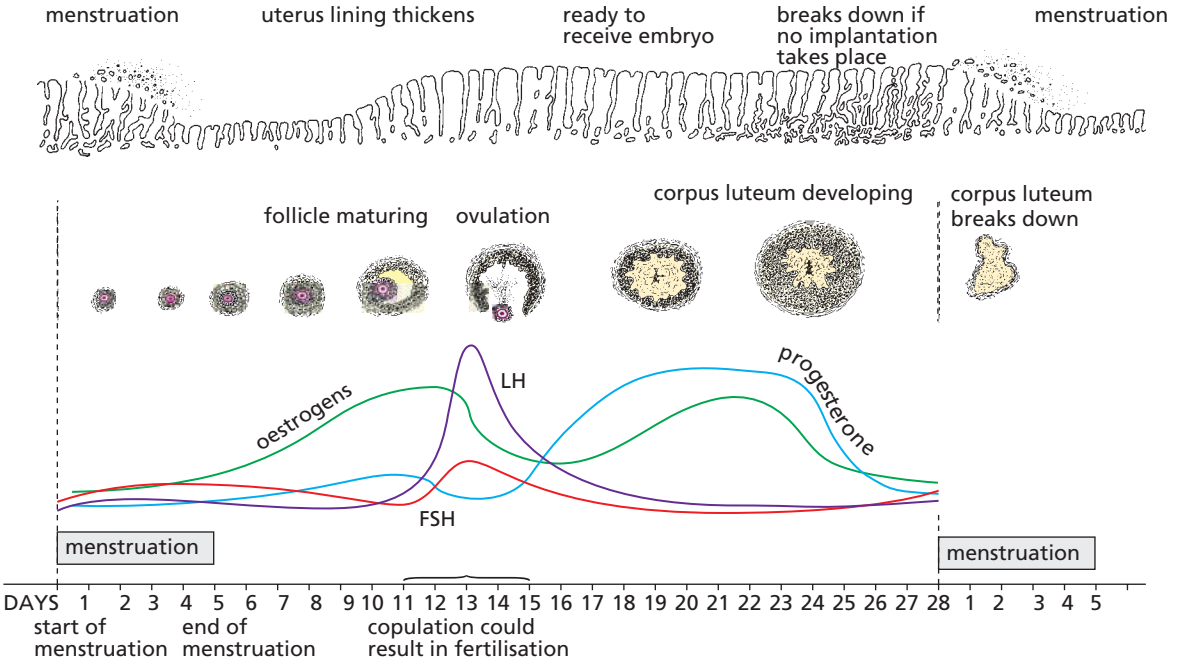
At the start of the cycle, the lining of the uterus wall has broken down (menstruation). **Follicle-stimulating hormone (FSH)** is then produced by the **pituitary gland** at the base of the brain and stimulates the growth of eggs in the ovaries in preparation for ovulation. As each follicle in the ovaries develops, the amount of oestrogens produced by the ovary increases. The oestrogens act on the uterus and cause its lining to become thicker and develop more blood vessels. These are changes that help an early embryo to implant. **Luteinising hormone**, or **lutropin (LH)** is then released from the pituitary gland. Its role is to trigger the release of the egg cell from an ovary at ovulation.

Once the egg cell has been released, the follicle that produced it develops into a solid body called the corpus luteum. This produces a hormone called progesterone, which affects the uterus lining in the same way as the oestrogens, making it grow thicker and produce more blood vessels.

If the egg cell is fertilised, the corpus luteum continues to release progesterone. While progesterone levels are high, the lining of the uterus is kept in a state that makes it suitable for implantation. If the egg cell is not fertilised, the corpus luteum stops producing progesterone. As a result, the thickened lining of the uterus breaks

down and loses blood, which escapes through the cervix and vagina. The events in the menstrual cycle are shown in Figure 16.67.

During pregnancy, the placenta takes over the role of secreting progesterone from the corpus luteum. The ovaries continue to secrete oestrogen.



▲ **Figure 16.67** The menstrual cycle

Test yourself

20 If a woman starts ovulating at 13 years old and stops at 50, without any pregnancies, calculate how many eggs are likely to be released from her ovaries.

21 One of the first signs of pregnancy is that the menstrual periods stop. Explain why you would expect this.

22 Construct a table to compare the sites of production of oestrogen and progesterone in the menstrual cycle and in pregnancy.

Revision checklist

After studying Chapter 16 you should know and understand the following:

Nuclear division

- ✔ Chromosomes contain DNA, which carries genetic information in the form of genes.
- ✔ In a diploid cell there is a pair of each type of chromosome; in a human diploid cell there are 23 pairs.
- ✔ In a haploid cell there is only one of each type of chromosome; in a human diploid cell there are 23 pairs of chromosomes.
- ✔ Mitosis is nuclear division giving rise to genetically identical cells in which the chromosome number is maintained.
- ✔ Mitosis is important in growth, repair of damaged tissues, replacement of cells and asexual reproduction.
- ✔ The exact replication of chromosomes occurs before mitosis.
- ✔ During mitosis, the copies of chromosomes separate, maintaining the chromosome number in each daughter cell.
- ✔ Stem cells are unspecialised cells that divide by mitosis to produce daughter cells that can become specialised for specific functions.
- ✔ Meiosis is a reduction division in which the chromosome number is halved from diploid to haploid, resulting in genetically different cells.

- ✔ Meiosis is involved in producing gametes.
- ✔ Cancers form as a result of uncontrolled cell division.

Asexual reproduction

- ✔ Asexual reproduction is a process resulting in the production of genetically identical offspring from one parent.
- ✔ Asexual reproduction occurs without gametes or fertilisation.
- ✔ The runner of the strawberry plant is a horizontal stem that grows above the ground, takes root at the nodes and produces new plants.
- ✔ The couch grass rhizome is a horizontal stem that grows below the ground and sends up shoots from its nodes.
- ✔ Bulbs are condensed shoots with circular fleshy leaves. Bulb-forming plants reproduce asexually from lateral buds.
- ✔ Rhizomes, corms, bulbs and tap roots may store food, which is used to speed up early growth.
- ✔ Asexual reproduction is fast and keeps the characteristics of the organism the same from one generation to the next, but does not result in variation to cope with environmental change.

Sexual reproduction

- ✔ Sexual reproduction is a process involving the fusion of the nuclei of two gametes to form a zygote and the production of offspring that are genetically different from each other.
- ✔ The male gamete is small and mobile. The female gamete is larger and not often mobile.
- ✔ Fertilisation is the fusion of gamete nuclei.
- ✔ The nuclei of gametes are haploid and the nucleus of the zygote is diploid.
- ✔ There are advantages and disadvantages of asexual reproduction and sexual reproduction.

Sexual reproduction in plants

- ✔ Flowers contain the reproductive organs of plants.
- ✔ The stamens are the male organs. They produce pollen grains, which contain the male gamete.
- ✔ The carpels are the female organs. They produce ovules, which contain the female gamete and will form the seeds.
- ✔ The flowers of most plant species contain male and female organs. A few species have unisexual flowers.
- ✔ Pollination is the transfer of pollen grains from an anther to a stigma.
- ✔ Fertilisation occurs when a pollen nucleus fuses with a nucleus in an ovule.
- ✔ Self-pollination is the transfer of pollen grains from the anther of a flower to the stigma of the same flower or different flower on the same plant.
- ✔ Cross-pollination is the transfer of pollen grains from the anther of a flower to the stigma of a flower on a different plant of the same species.
- ✔ Self-pollination and cross-pollination have implications to a population.
- ✔ Pollination may be carried out by insects or by the wind.
- ✔ Flowers that are pollinated by insects are usually brightly coloured and have nectar.
- ✔ Flowers that are pollinated by the wind are usually small and green. Their stigmas and anthers hang outside the flower where they are exposed to air movements.
- ✔ Fertilisation occurs when a pollen tube grows from a pollen grain into the ovary and up to an ovule. The pollen nucleus passes down the tube and fuses with the ovule nucleus.
- ✔ After fertilisation, the ovary grows rapidly to become a fruit and the ovules become seeds.
- ✔ A seed includes an embryo (radicle, plumule and cotyledons) and testa.
- ✔ Seed and fruit dispersal by wind and by animals is a means of colonising new areas and of reducing competition.
- ✔ Germination is influenced by temperature and the amount of water and oxygen available.

Sexual reproduction in humans

- ✔ The male human reproductive system consists of testes, scrotum, sperm ducts, prostate gland, urethra and penis. Each has a role in reproduction.
- ✔ The female human reproductive system consists of ovaries, oviducts, uterus, cervix and vagina. Each has a role in reproduction.
- ✔ The male reproductive cells (gametes) are sperm. They are produced in the testes and expelled through the urethra and penis during mating.
- ✔ The female reproductive cells (gametes) are eggs. They are produced in the ovaries. One is released each month. If sperm are present, the egg cell may be fertilised as it passes down the oviduct to the uterus.

- ✔ Eggs and sperm are different in size, structure, mobility and numbers produced.
- ✔ Sperm and eggs have special features to adapt them for their functions.
- ✔ Fertilisation is the fusion of the nuclei from a sperm and an egg cell.
- ✔ The fertilised egg cell (zygote) forms an embryo and becomes embedded in the lining of the uterus.
- ✔ The embryo gets its food and oxygen from its mother.
- ✔ Parts develop to support the fetus.
- ✔ The embryo's blood is pumped through blood vessels in the umbilical cord to the placenta, which is attached to the uterus lining.
- ✔ The placenta and umbilical cord are involved in the exchange of materials between the mother and fetus.
- ✔ Some toxins and viruses can pass across the placenta and affect the fetus.

Sexual hormones in humans

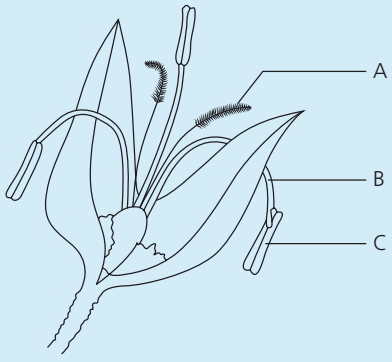
- ✔ At puberty, the testes and ovaries start to produce mature gametes and the secondary sexual characteristics develop.
- ✔ The hormones testosterone and oestrogen control the development and regulation of secondary sexual characteristics during puberty.
- ✔ Each month, the uterus lining thickens up in readiness to receive a fertilised egg cell. If an egg cell is not fertilised, the lining and some blood are lost through the vagina. This is menstruation.
- ✔ Follicle-stimulating hormone (FSH), luteinising hormone (LH), oestrogen and progesterone control the menstrual cycle.

Exam-style questions

1 State which structures in a flower produce
- **a** the male gametes [1]
- **b** the female gametes. [1]

2 **a** Distinguish between the terms *pollination* and *fertilisation*. [4]
- **b** In flowering plants
  - **i)** can pollination occur without fertilisation
  - **ii)** can fertilisation occur without pollination? Give reasons for your answers. [2]

3 The diagram shows the structure of a flower.



- **a** **i)** Identify the structures A, B and C. [3]
  - **ii)** Name the flower part made up of structures B and C. [1]
- **b** State the type of pollination most likely to be carried out in this flower. With reference to structures A, B and C, explain your answer. [5]

4 Construct a table to compare the features of reproduction in flowering plants and humans. Include the following features:
- male reproductive organs
- female reproductive organs
- male gamete
- female gamete
- place where fertilisation occurs
- what a zygote grows into. [5]

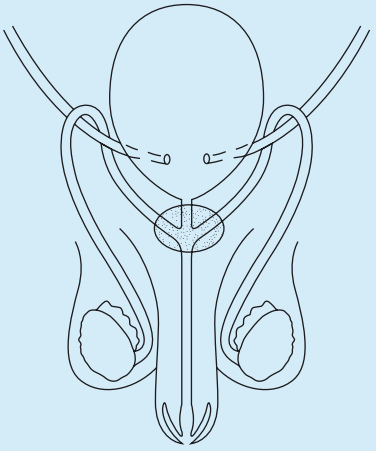
5 A gardener finds a new and attractive plant produced as a result of a chance mutation. Explain whether she should attempt to produce more of the same plant by self-pollination or by taking cuttings (asexual reproduction). [2]

6 **a** Describe the advantages to an organism of asexual reproduction. [3]
- **b** Outline the advantages of asexual reproduction to crop production. [2]

7 Describe how the composition of the blood in the umbilical vein (passing from the mother to the fetus) is different from that in the umbilical artery (passing from the fetus to the mother). [4]

8 **a** **i)** State the functions of the placenta. [3]
- **ii)** Suggest what features must be present in the placenta to allow transfer of materials by diffusion. [3]
- **b** Explain why it is important that the blood of the fetus and mother do not mix. [2]

9 The diagram shows the male reproductive system.



- **a** **i)** On the diagram, label **five** parts of the reproductive system. [5]
  - **ii)** State the functions of the parts you have labelled. [5]
- **b** Explain how sperm, deposited in the vagina during sexual intercourse, reach an egg. [4]

10 Explain how menstruation is prevented if an embryo becomes implanted in the uterus lining. [3]

17 Inheritance

Focus

When you look at a crowd of people, although they are all the same species, you can see a wide range of differences between them. It is the same with most other species of animals and plants as well. What causes this variation? Is it always possible to pass features on to our children? We often talk about people inheriting certain characteristics: 'Anwar has inherited his father's curly hair', or 'Fatima has inherited her mother's brown eyes'. We expect tall parents to have tall children. In this chapter we will explore how we inherit characteristics. You are about to find out more about a branch of biology that studies how heredity works. It is called genetics.

Variation

FOCUS POINTS

- ★ What is variation?
- ★ What does continuous variation result in?
- ★ What does discontinuous variation result in?
- ★ What are discontinuous and continuous variation usually caused by?
- ★ What are examples of continuous and discontinuous variation?

Key definitions

Variation is the differences between individuals of the same species.

The term variation refers to observable differences within a species. All domestic cats belong to the same species, i.e. they can all interbreed, but there are many variations of size, coat colour, eye colour, fur length, etc. Some variations are inherited and these are controlled by genes. They are **genetic** variations. **Phenotypic** variations may be produced by genes but can also be caused by the environment, or a combination of both genes and the environment.

So, there are variations that are not heritable but brought about by factors in the environment. A kitten that does not get enough food will not grow to the same size as other well-fed kittens in the same litter. A cat with a skin disease may have bald patches in its coat. These conditions cannot be inherited. They are caused by environmental effects. In the same way, a fair-skinned person may be able to change the colour of his or her skin by exposing it to the Sun and getting a tan. The tan is an acquired characteristic. You cannot inherit a suntan. Black skin, on the other hand, is an **inherited** characteristic.

Many features in plants and animals are a mixture of acquired and inherited characteristics (Figure 17.1). For example, some fair-skinned people never go brown in the Sun, they only become sunburned. They have not inherited the genes for producing the extra brown pigment in their skin. A fair-skinned person with the genes for producing pigment will only go brown if he or she exposes themselves to sunlight. So, the tan is a result of both inherited and acquired characteristics.

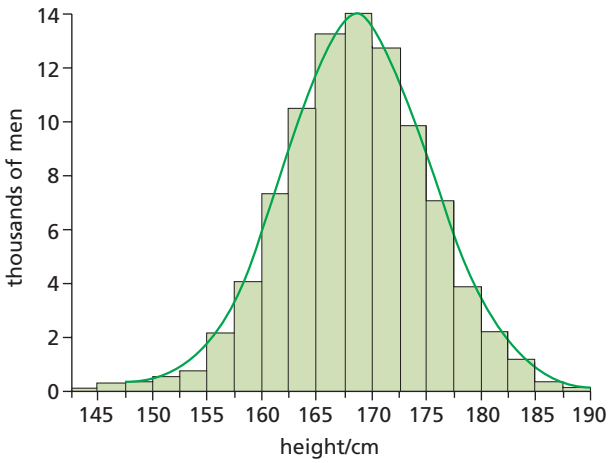
Continuous variation

Continuous variation is influenced by a combination of both genetic and environmental factors. An example of continuous variation is height. There are no distinct categories of height; people are not either tall or short. There are all possible intermediates between very short and very tall (Figure 17.2).

▲ **Figure 17.1** Acquired characteristics. These apples have all been picked from different parts of the same tree. All the apples have similar genotypes, so the differences in size must have been caused by environmental effects

Continuously variable characteristics are usually controlled by several pairs of **alleles** (see later in this chapter). There might be five pairs of alleles for height – (**Hh**), (**Tt**), (**Ll**), (**Ee**) and (**Gg**) – each dominant allele adding 4 cm to your height. If you inherited all ten dominant genes (**HH**, **TT**, etc.) you could be 40 cm taller than a person who inherited all ten **recessive** genes (**hh**, **tt**, etc.).

Scientists do not know the actual number of genes that control height, intelligence and even the colour of hair and skin.

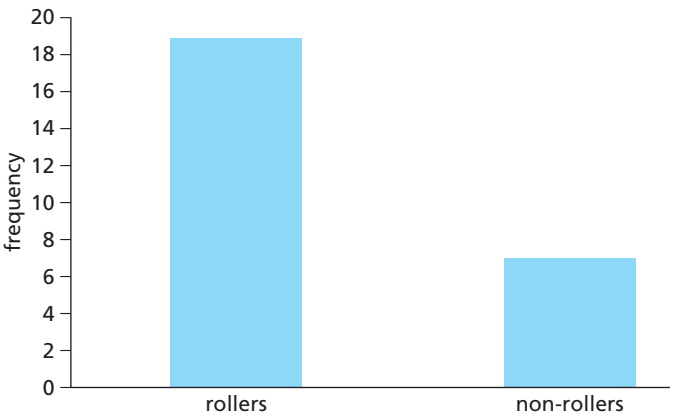


▲ **Figure 17.2** Continuous variation. Heights of 90000 army recruits. The apparent steps in the distribution are the result of randomly chosen categories, differing in height by 1 cm. But heights do not differ by exactly 1 cm. If measurements could be made accurately to the nearest millimetre there would be a smooth curve like the one shown in colour

Continuously variable characteristics are strongly influenced by the environment. A person may inherit genes for tallness but they may not get enough food to grow tall. A plant may have the genes for large fruits but not get enough water, mineral ions or sunlight to produce large fruits. Continuous variations in human populations, like height, physique and intelligence, are always the result of contributions from both the **genotype** and the environment.

Discontinuous variation

In **discontinuous variation**, the variations take the form of distinct, alternative phenotypes with no intermediates (Figures 17.3 and 17.4). Pea seeds may be wrinkled or smooth and their colour can be yellow or green. The mice in Figure 17.20 are either black or brown; there are no intermediates. You are either male or female. Apart from a small number of exceptions, sex is inherited in a discontinuous way. Some people can roll their tongue into a tube. Others are unable to do it. They are known as non-tongue rollers. Again, there are no intermediates (Figure 17.3). **Note:** This is an over-simplification and there may be some environmental factors involved as well. Some children gradually develop the ability to roll their tongue as they get older.

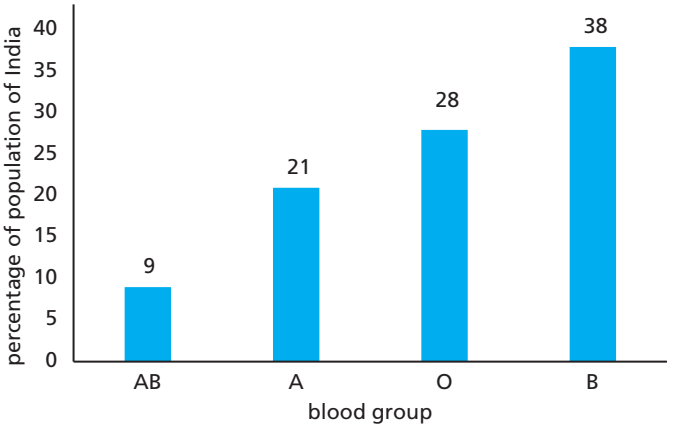


▲ **Figure 17.3** Discontinuous variation. Tongue rollers and non-rollers in a class

Discontinuous variation cannot usually be altered by the environment. You cannot change your eye colour by altering your diet. A genetic dwarf cannot grow taller by eating more food.

Discontinuous variation is under the control of a single pair of alleles or a small number of genes. An example is human blood groups. A person is one of four blood groups: A, B, AB or O. There are no groups in between.

There are many characteristics that are difficult to classify as either completely continuous or discontinuous variations. Human eye colour has already been mentioned. People can be classified roughly as having blue eyes or brown eyes, but there are also categories described as grey, hazel or green. It is likely that there are a small number of genes for eye colour and a dominant gene for brown eyes, which overrides all the others when it is present. Similarly, red hair is a discontinuous variation. However, it is hidden by genes for other colours and there is a continuous range of hair colour from blond to black.



▲ **Figure 17.4** Discontinuous variation. Frequencies of ABO blood groups in India. The figures could not be adjusted to fit a smooth curve because there are no intermediates. **Note:** The figures do not add up to 100% because there are other less common blood groups as well

Practical work

1 Collecting data about variation in a group of people

Create a table to collect data on variation among a group of people. This could be members of your class or people you live or work with.

You will need a ruler and tape measure.

Set up headings for the table, such as:

name	eye colour	tongue roller?	hand span (cm)	shoe size	height (cm)

When you have collected the data each characteristic needs to be grouped and tallied.

For example, for eye colour, count how many people have blue, brown, hazel or green eyes.

Variation in height is more difficult when organising the data. You will need to look at the range of data you have collected then choose categories between the smallest and largest height. For example, if your range is 156–193 cm, the categories could be:

- 155–159
- 160–164
- 165–169
- 170–174
- 175–179
- 180–184
- 185–189
- 190–194.

It is tempting to make the categories simpler for example, 5s, so 155–160, 160–165 and so on. However, if you did this, in which category would you place a person who is 160 cm tall?

After organising the data it needs to be plotted on a graph.

The data for tongue rolling and eye colour is in distinct categories (categoric). Each data set needs to be plotted as a bar chart. In a bar chart the columns do not touch each other (see Figure 17.4).

The data for hand span, shoe size and height is continuous (numerical). The frequencies for the different values should be plotted as a histogram, where each of the blocks touches the next (see Figure 17.2).

Results

Some frequencies for each set of data will be larger than others. For characteristics like shoe size, there may be a normal distribution, where a few individuals have small or large feet and the majority are clustered around the middle of the range. However, this is the ideal and will depend on the data size: a large set of data is more likely to show a normal distribution.

Interpretation

Some of the data collected (tongue rolling and eye colour) will represent examples of discontinuous variation. However, hand span, shoe size and height are examples of continuous variation.

Practical work questions

1 Describe what each graph shows and write a conclusion. The conclusion can be based on the most common results and the type of variation the data shows. If you do not have any data, base your descriptions and conclusions on Figures 17.2, 17.3 and 17.4.
2 Make a list of other variable features shown by members of your class that you could collect data for.

Test yourself

1 Outline the differences between discontinuous and continuous variation.
2 Give two examples of discontinuous and continuous variation in humans.

DNA

FOCUS POINTS

- ★ What is the structure of DNA?
- ★ What is a gene?
- ★ How does DNA control cell function?
- ★ How does the base sequence in a gene determine the sequence of amino acids in a protein?

Key definitions

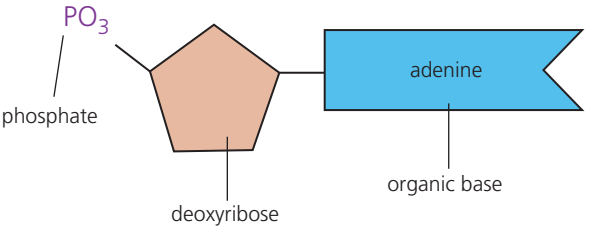
A **gene** is a length of DNA that codes for a protein.

A DNA molecule is made up of long chains of **nucleotides** (Figure 17.5), formed into two strands. In DNA the sugar is deoxyribose and the organic base is either adenine (A), thymine (T), cytosine (C) or guanine (G).

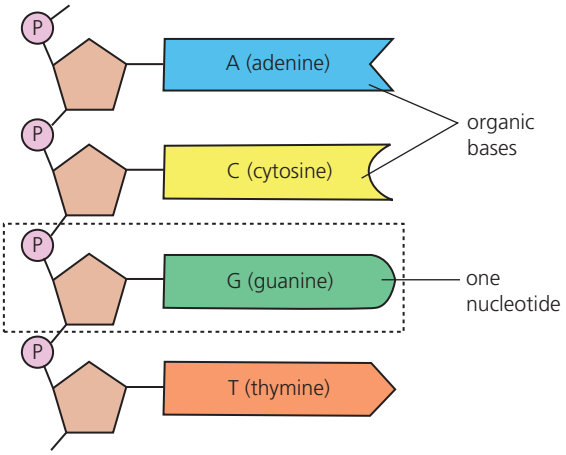
Note: For exam purposes, it is only necessary to be able state the letters, *not* the names of these bases.

The nucleotides are joined by their phosphate groups to make a long chain, often thousands of nucleotides long. The phosphate and sugar molecules are the same all the way down the chain. However, the bases can be any one of the four listed (Figure 17.6).

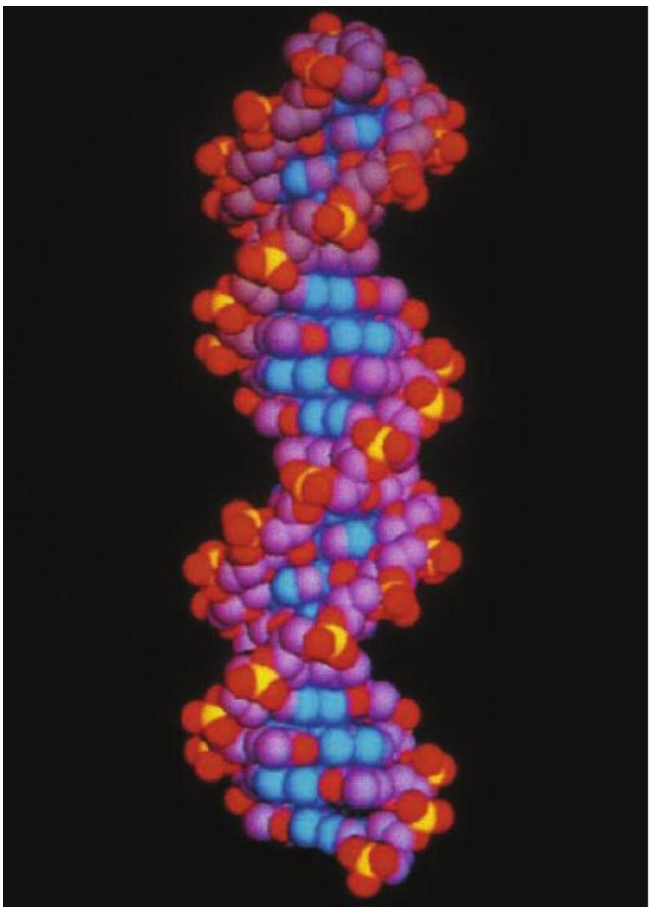
The DNA in a chromosome is made of two strands (chains of nucleotides) held together by chemical bonds between the bases. The size of the molecules makes sure that A always pairs with T and C pairs with G. The double strand is twisted to make a helix (like a twisted rope ladder with the base pairs being the rungs) (Figures 17.7 and 17.8).



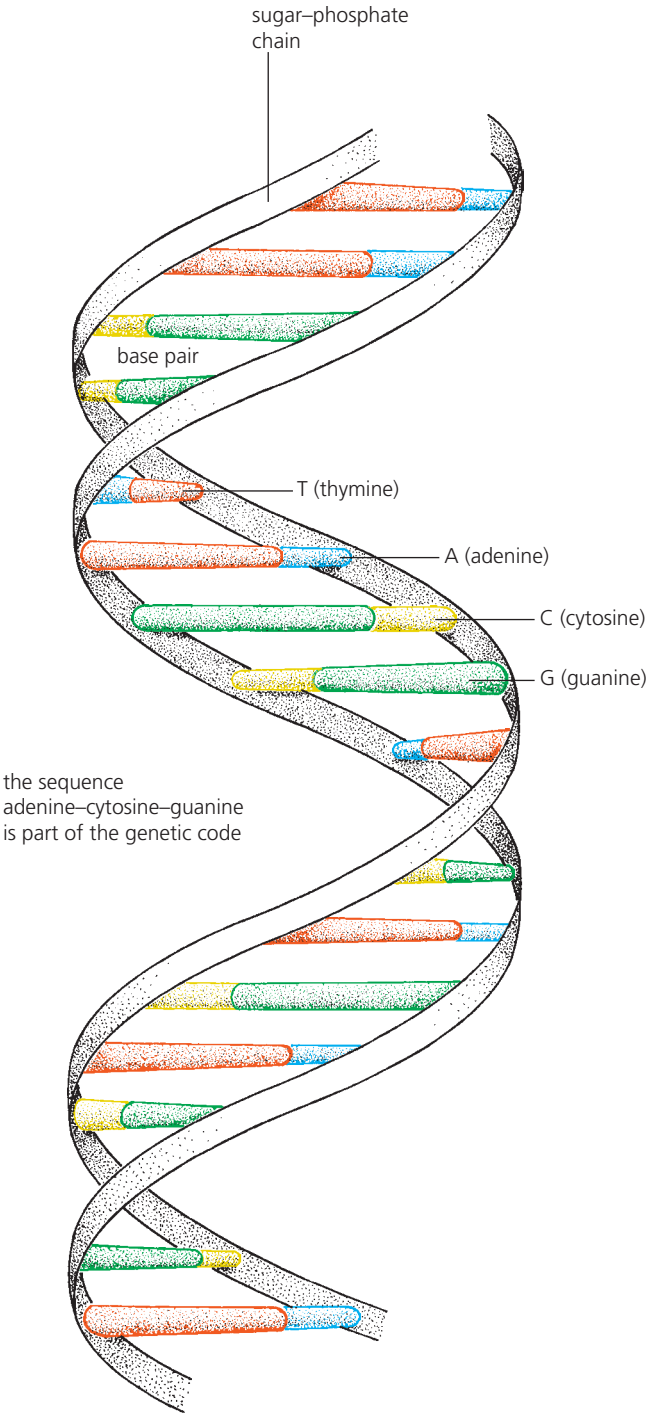
▲ **Figure 17.5** A nucleotide (adenosine monophosphate)



▲ **Figure 17.6** Part of a DNA molecule with four nucleotides



▲ **Figure 17.7** Model of the structure of DNA



▲ **Figure 17.8** This schematic shows part of a DNA molecule

Going further

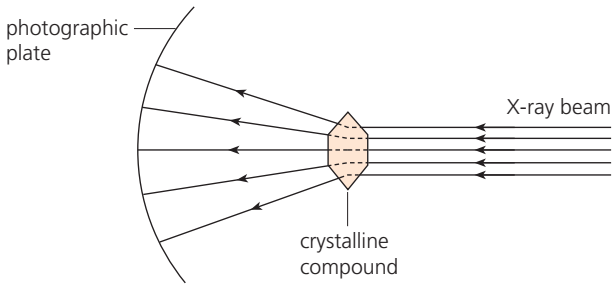
DNA

In 1869, a chemist working on cell chemistry discovered a compound that contained nitrogen and phosphorus (as well as carbon). This was an unusual combination. The substance came from nuclei and was first called 'nuclein' and then 'nucleic acid'. Further studies showed nucleic acid contained the bases adenine, thymine, cytosine and guanine, as well as a carbohydrate later identified as deoxyribose. In the early 1900s, scientists identified the structure of nucleotides (base–sugar–phosphate, Figure 17.6) They also found how they linked up to make deoxyribonucleic acid (DNA).

In the 1940s, a chemist called Chargaff studied a sample of DNA. He found that the number of adenines (A) are always the same as the number of thymines (T). In the same way, the amounts of cytosine (C) and guanine (G) are always equal. Crick and Watson used this information to work out the structure of DNA.

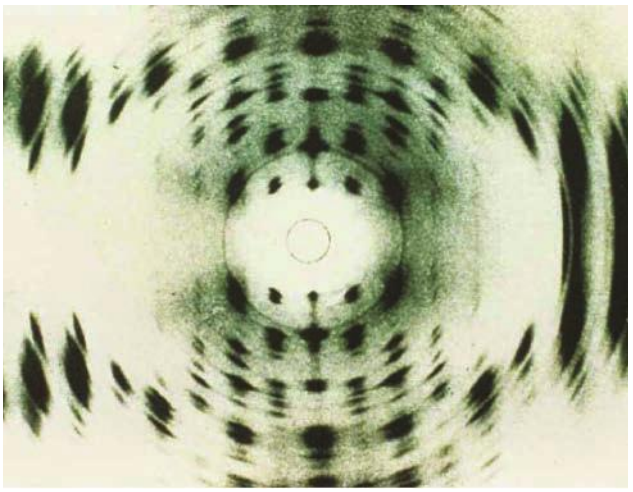
The British physicist, Francis Crick, and American biologist, James Watson, worked together in the Cavendish Laboratory at Cambridge in the 1950s. They did not do chemical analyses or experiments. Instead, they used the data from X-ray crystallography and the chemistry of nucleotides to try out different models for the structure of DNA.

The regular pattern of atoms in a crystal scatters a beam of X-rays. This allows the structure of the molecules in the crystal to be found (Figure 17.9). The scattered X-rays are directed on to a photographic plate. When developed the plate shows images like the one in Figure 17.10.



Simplified image of the scattering of X-rays by crystalline structures

▲ **Figure 17.9** X-ray crystallography



▲ **Figure 17.10** One of the images produced by X-rays scattered by DNA. The number and positions of the dark areas allows the molecular structure to be calculated

The scientists took careful measurements of the spots on the photograph. Using some complicated mathematics, they found the molecular structure of many compounds.

A crystalline form DNA was treated in the same way. Most of the necessary X-ray crystallography was carried out by Maurice Wilkins and Rosalind Franklin at King's College, London.

Crick and Watson made models on a trial-and-error basis. They judged each model on how well it matched the X-ray measurements and the chemical properties of the parts of the molecule.

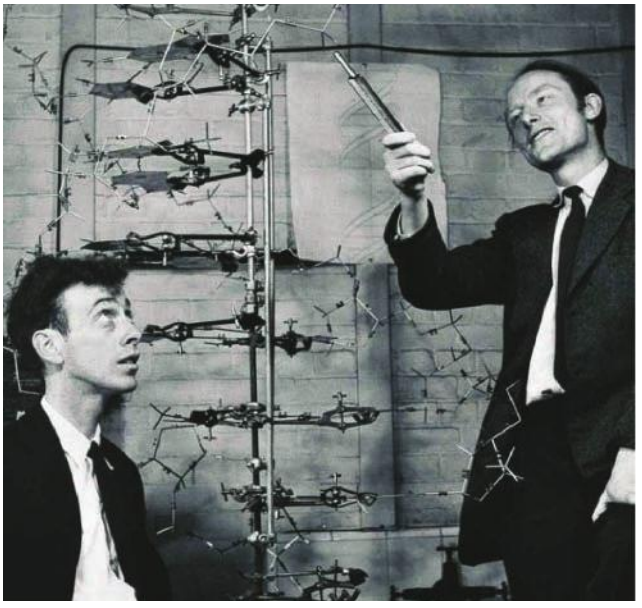
The evidence suggested a helical structure (like a spiral staircase). At first, they tried models with a core of three or four nucleotide chains twisted around each other. The bases were attached to the outside.

However, these models did not fit the X-ray data or the chemical structures of the nucleotides. Watson tried a two-chain helical model with the bases pointing inwards. First, he paired adenine (A) with adenine (A), cytosine (C) with cytosine (C), etc. But thymine (T) and cytosine (C) were smaller molecules than adenine (A) and guanine (G). He found that this pairing would alter the shape of the double helix.This is where Chargaff's

work helped. If there were equal numbers of adenine (A) and thymine (T), and equal numbers of cytosine (C) and guanine (G), this pairing of bases, large plus small, would fit inside the sugar–phosphate double helix without altering its shape.

The X-ray data confirmed that the diameter of the helix would allow this pairing. Also, the chemistry of the bases would allow them to hold together. The outcome is the model of DNA shown in Figures 17.6, 17.7 and 17.8.

Crick, Watson and Wilkins were awarded the Nobel Prize for medicine and physiology in 1962. Unfortunately, Rosalind Franklin died in 1958, so she did not receive an award for the work she did.



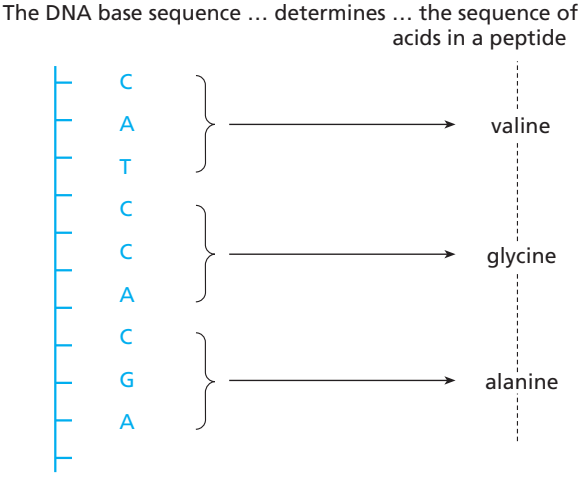
▲ **Figure 17.11** Crick (right) and Watson with their model of the DNA molecule

The genetic code

Each nucleotide carries one of four bases (A, T, C or G). So, a string of nucleotides holds a sequence of bases. This sequence forms a code, which instructs the cell to make specific proteins. DNA controls cell function by controlling the production of proteins, including enzymes. Proteins are made from amino acids linked together (Chapter 4). The type and sequence of the amino acids joined together will determine the kind of protein formed. For example, one protein molecule may start with the sequence *alanine–glycine–glycine* ... A different protein may start *glycine–serine–alanine* ...

The sequence of bases in the DNA molecule controls which amino acids are used and in which order they are joined. Different sequences of amino acids give different shapes to protein molecules. Each group of three bases stands for one amino acid, for example, the triplet of bases CGA codes for the amino acid *alanine*, the base triplet CAT codes for the amino acid *valine*, and the triplet CCA codes for *glycine*. The tri-peptide *valine–glycine–alanine* is coded by CAT–CCA–CGA (Figure 17.12).

So, a gene is a sequence of triplets of the four bases, which codes for a complete protein. Insulin is a small protein with only 51 amino acids. A sequence of 153 (i.e. 3 × 51) bases in the DNA molecule would represent the gene that makes an islet cell in the pancreas produce insulin. Most proteins are much larger than this and most genes contain a thousand or more bases.



▲ **Figure 17.12** The genetic code (triplet code)

The chemical reactions that take place in a cell define what sort of a cell it is and what its functions are. These chemical reactions are, in turn, controlled by enzymes. Enzymes are proteins. So, the genetic code of DNA determines which proteins, particularly enzymes, are produced in a cell. It also determines the cell's structure and function. In this way, the genes determine the structure and function of the whole organism.

Other proteins coded for in DNA include antibodies, membrane carriers and the receptors for neurotransmitters (see details of synapses in Chapter 14).

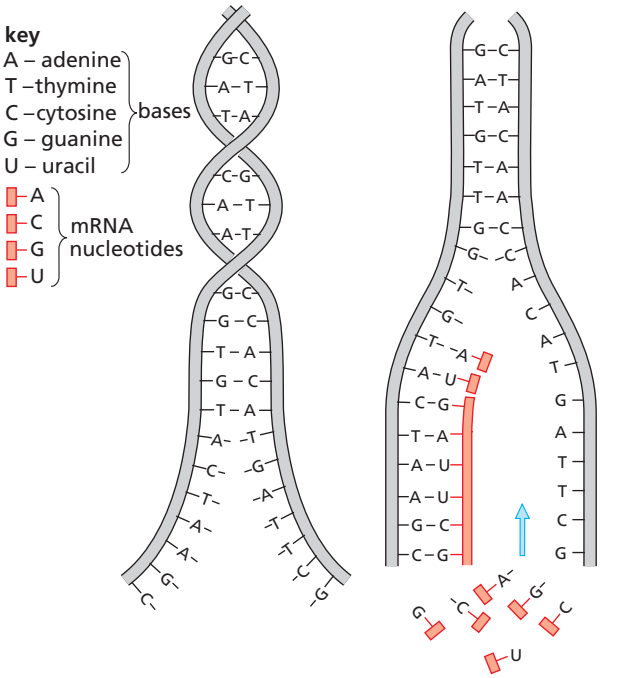
Going further

The manufacture of proteins in cells

DNA molecules remain in the nucleus, but the proteins they code for are needed in other parts of the cell. A molecule called messenger RNA (mRNA) is used to transfer the information from the nucleus. It is much smaller than a DNA molecule and is made up of only one strand. Another difference is that mRNA molecules contain slightly different bases (A, C, G and U). Base U is uracil. It attaches to the DNA base A.

To pass on the protein code, the double helix of DNA (see Figure 17.8) unwinds to expose the chain of bases. One strand acts as template. A messenger RNA molecule is formed along part of this strand. It is made up of a chain of nucleotides with complementary bases to a section of the DNA strand (Figure 17.13). The mRNA molecule carrying the protein code then passes out of the nucleus, through a nuclear pore in the membrane to the cytoplasm. Once in the cytoplasm it attaches itself to a **ribosome**. Ribosomes make proteins. The mRNA molecule instructs the ribosome to put together a chain of amino acids in a specific sequence to make a protein. Other mRNA molecules will carry codes for different proteins.

Some proteins are made up of quite a small number of amino acids. As stated, insulin is a chain of 51 amino acids. On the mRNA molecule each amino acid is coded by a sequence of three bases (a triplet), so the mRNA molecule coding for insulin will contain 153 bases.



(a) The DNA helix unwinds: the strands separate, exposing the bases.

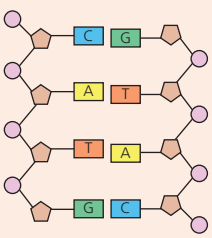
(b) mRNA nucleotides attach to the exposed DNA bases to form an mRNA molecule.

▲ **Figure 17.13** Formation of messenger RNA

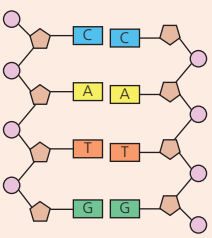
Test yourself

3 Which diagram shows part of a DNA molecule with all the bases bonded correctly?

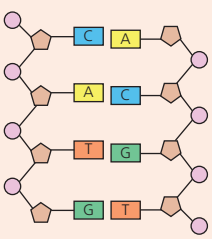
A



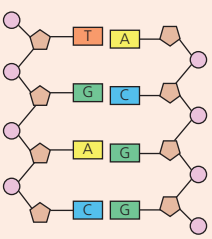
B



C



D



4 Which units are present in a nucleotide of DNA?
- **A** phosphate, glucose, base
- **B** phosphate, deoxyribose, base
- **C** deoxyribose, base, amino acid
- **D** glucose, fatty acid, base

5 Which statement about a DNA molecule is correct?
- **A** Each strand is made of chains of glucose molecules.
- **B** Base A bonds with base C.
- **C** The number of C bases equals the number of G bases.
- **D** The molecule is made up of straight, parallel strands.

6 Outline how a protein is made.

Going further

Gene expression

Body cells do not all have the same requirements for proteins. For example, the function of some cells in the stomach is to make the protein pepsin (see Chapter 8). Bone marrow cells make the protein haemoglobin but do not need digestive enzymes. Specialised cells all contain the same genes in their nuclei, but only the genes needed to code for specific proteins are expressed (switched on). This enables the cell to make only the proteins it needs to carry out its function.

Inheritance

FOCUS POINTS

- ★ What do the following terms mean: inheritance, genotype, phenotype, homozygous, heterozygous, dominant, recessive?
- ★ What happens when two identical homozygous individuals breed together?
- ★ What happens when a heterozygous individual breeds?
- ★ How would you use Punnett squares in crosses to work out and show the possible different genotypes?
- ★ How is sex inherited in humans?
- ★ What are codominance characteristics?
- ★ How are ABO blood groups inherited?
- ★ How would you use genetic diagrams to predict the results of monohybrid crosses, including those that involve codominance, and calculate phenotypic ratios?
- ★ Why do observed ratios differ from expected ratios?
- ★ What is gene mutation and what is chromosome mutation?
- ★ What are sources of genetic variation in populations?
- ★ What increases the rate of mutation?

Key definitions

Inheritance is the transmission of genetic information from generation to generation.

An **allele** is an alternative form of a gene.

Genotype is the genetic make-up of an organism in terms of the alleles present.

Phenotype is the observable features of an organism.

Homozygous means having two identical alleles of a particular gene.

Heterozygous means having two different alleles of a particular gene.

Dominant describes an allele that is expressed if it is present in the genotype.

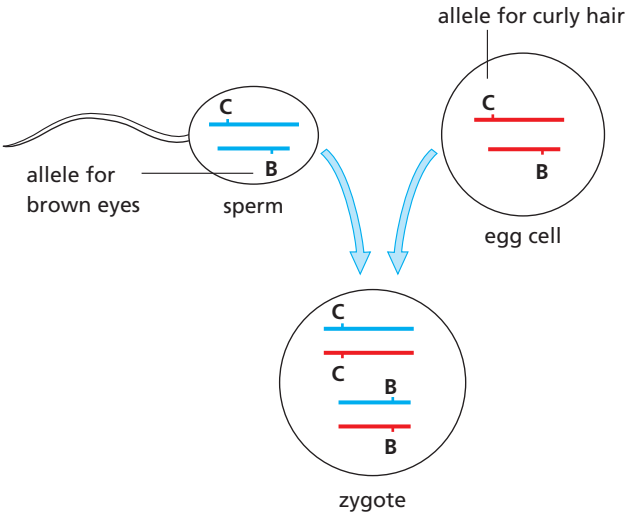
Recessive describes an allele that is only expressed when there is no dominant allele of the gene present in the genotype.

It is very important to be familiar with the terms associated with inheritance. Key terms are given above. Also, remember from earlier in this chapter that a gene is a length of DNA that codes for a protein and an allele is a version of a gene.

Patterns of inheritance

The allele in a mother's body cells that causes her to have brown eyes may be present on one of the chromosomes in each egg cell she produces. If the father's sperm cell contains an allele for brown eyes on the corresponding chromosome, the zygote will receive an allele for brown eyes from each parent. These alleles will be reproduced by cell division in all the embryo's body cells. When the embryo's eyes develop, the alleles will make the cells of the iris produce brown pigment (melanin) and the child will have brown eyes. In a similar way, the child may receive alleles for curly hair.

Figure 17.14 shows this happening, although it is very simplified – it does not show all the other chromosomes with thousands of genes for producing the enzymes making different types of cell and all the other processes that control the development of the organism.

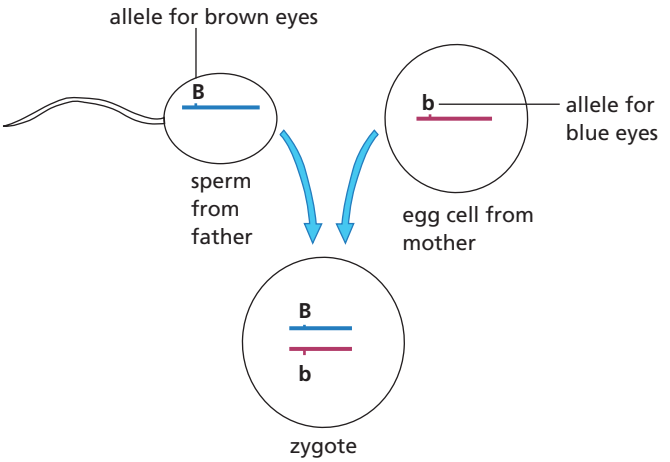


▲ **Figure 17.14** Fertilisation brings the chromosomes back to the diploid number and combines the alleles from the mother and father

Single-factor inheritance

It is impossible to follow the inheritance of the thousands of characteristics controlled by genes. So, we will start with the study of a single gene that controls one characteristic. We have used eye colour as an example so far. Probably more than one allele pair is involved, but the simplified example is straightforward to follow. It has already been explained how an allele for brown eyes from each parent results in the child having brown eyes. However, suppose that the mother has blue eyes and the father brown eyes. The child might receive an allele for blue eyes from its mother and an allele for brown eyes from its father (Figure 17.15). If this happens, the child will have brown eyes, although you might think having blue eyes should be equally possible. The allele for brown eyes is said to be dominant to the allele for blue eyes. Although the allele for blue eyes is present in all the child's cells, it is not expressed. It is said to be recessive to brown.

Eye colour is a useful model for explaining inheritance but it is not totally reliable because blue eyes vary a lot in colour and sometimes contain small amounts of brown pigment.



▲ **Figure 17.15** Combination of alleles in the zygote (only one chromosome is shown). The zygote has both alleles for eye colour; the child will have brown eyes

This example illustrates the following important points:

- There is a pair of alleles for each characteristic, one allele from each parent.
- Although the allele pairs control the same characteristic (e.g. eye colour) they may have different effects. One tries to produce blue eyes, the other tries to produce brown eyes.
- Often one allele is dominant over the other.
- The alleles of each pair are on corresponding chromosomes and occupy corresponding positions. For example, in Figure 17.14 the alleles for eye colour are shown in the corresponding position on the two short chromosomes. The alleles for hair curliness are in corresponding positions on the two long chromosomes. In diagrams and explanations of heredity
  - alleles are represented by letters
  - alleles controlling the same characteristic are given the same letter
  - the dominant allele is given the capital letter.

For example, in rabbits, the dominant allele for black fur is labelled **B**. The recessive allele for white fur is labelled **b** to show that it corresponds to **B** for black fur. If it were labelled **w**, we would not see any connection between **B** and **w**. **B** and **b** are obvious partners. In the same way, **L** could represent the allele for long fur and **l** the allele for short fur.

Breeding true

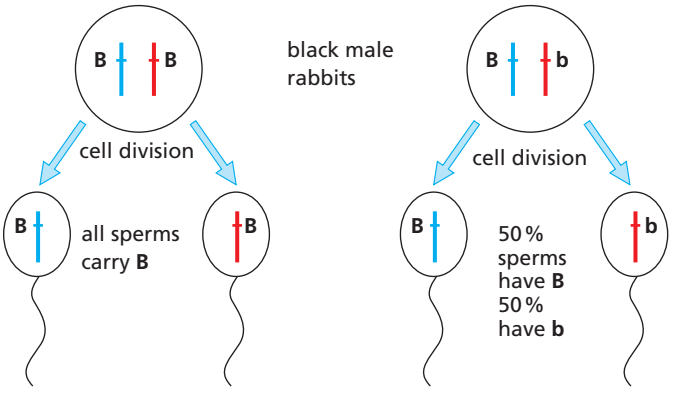
A white rabbit must have both the recessive alleles **b** and **b**. If it had **B** and **b**, the dominant allele for black (**B**) would dominate the allele for white (**b**) and produce a black rabbit. A black rabbit, on the other hand, could be either **BB** or **Bb** and, by just looking at the rabbit, you could not tell the difference. When a male black rabbit **BB** produces sperm, each one of the pair of chromosomes carrying the **B** alleles will end up in different sperm cells. Since the alleles are the same, all the sperm will have the **B** allele for black fur (Figure 17.16(a)).

A black rabbit **BB** is called a **pure-breeding** black and is said to be homozygous for black coat colour (*homo-* means *the same)*. If this rabbit mates with another black (**BB**) rabbit, all the babies will be black because all will receive a dominant allele for black fur. When all the offspring have the same characteristic as the parents, this is called pure breeding for this characteristic.

When a **Bb** black rabbit produces gametes by meiosis, the chromosomes with the **B** allele and the chromosomes with the **b** allele will end up in different gametes. So, 50% of the sperm cells will carry **B** alleles and 50% will carry **b** alleles (Figure 17.16(b)). Similarly, in the female, 50% of the eggs will have a **B** allele and 50% will have a **b** allele. If a **b** sperm fertilises a **b** egg cell, the offspring, with two **b** alleles (**bb**), will be white. The black **Bb** rabbits are not pure breeding because they may produce some white babies as well as black ones. The **Bb** rabbits are called heterozygous (*hetero-* means *different*).

The black **BB** rabbits are homozygous dominant.

The white **bb** rabbits are homozygous recessive.



▲ **Figure 17.16** Breeding pure

Genotype and phenotype

The two kinds of black rabbit **BB** and **Bb** have the same phenotype. This is because their coat colours look the same. However, because they have different allele pairs for coat colour, they have different genotypes, i.e. different combinations of alleles. One genotype is **BB** and the other is **Bb**.

Two brothers might both be brown-eyed phenotypes, but one brother's genotype could

Going further

Pedigree diagrams and inheritance

The term **pedigree** often refers to the pure-breeding nature of animals, but it is also used to describe human inheritance. Pedigree diagrams are like family trees and can be used to show how genetic diseases can be inherited. They include symbols to show whether individuals are male or female and what their genotype is for a certain genetic characteristic.

One genetic condition is called cystic fibrosis. The symptoms of cystic fibrosis are the production of very sticky mucus in the lungs. The problems of sticky mucus is that it can

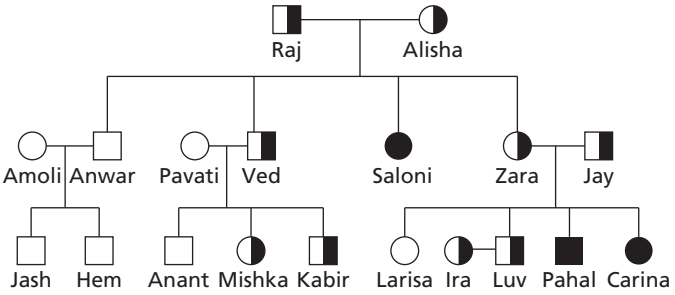
- make gas exchange more difficult
- trap microbes so the person suffering with cystic fibrosis gets respiratory diseases more often
- block ducts responsible for transferring enzymes into the small intestine
- block reproductive ducts, resulting in lower fertility or sterility.

People with cystic fibrosis tend to have a much shorter life span than normal, although treatment of the condition is becoming more effective and average life expectancies are improving.

A person with cystic fibrosis has received two recessive alleles (cc); one from each parent. A carrier of the condition has one normal allele and one recessive allele (Cc). This condition is not uncommon in Europe: 1 in 25 people of European descent is a carrier, but it is quite rare in the Indian subcontinent. A healthy person has two normal alleles (CC).

The pedigree diagram (Figure 17.17) shows the inheritance of cystic fibrosis in a family.

Parents Raj and Alisha are married and both are cystic fibrosis carriers. However, because carriers have no symptoms of the disease, they may be unaware that they have defective alleles for cystic fibrosis. They go on to have four children. Three of these children eventually get married and have children of their own. One child, Salomi, suffers from cystic fibrosis. The pedigree diagram shows that she does not get married and has no children.



▲ **Figure 17.17** Pedigree diagram to show the inheritance of cystic fibrosis in a family

It is possible for individuals in a family with a history of cystic fibrosis to have genetic counselling. In this process, the risk of having children with cystic fibrosis would be explained to the carriers and those with the condition. Developing embryos can be genetically screened to identify their genotype. A carrier with a partner who is also a carrier (like Ira and Luv in Figure 17.17) may choose not to have children because of the 1 in 4 chance of the inheritance of cystic fibrosis. Alternatives may be to foster or adopt children instead.

be **BB** and the other's could be **Bb**. One would be homozygous dominant for brown eyes; the other would be heterozygous for eye colour.

Alleles

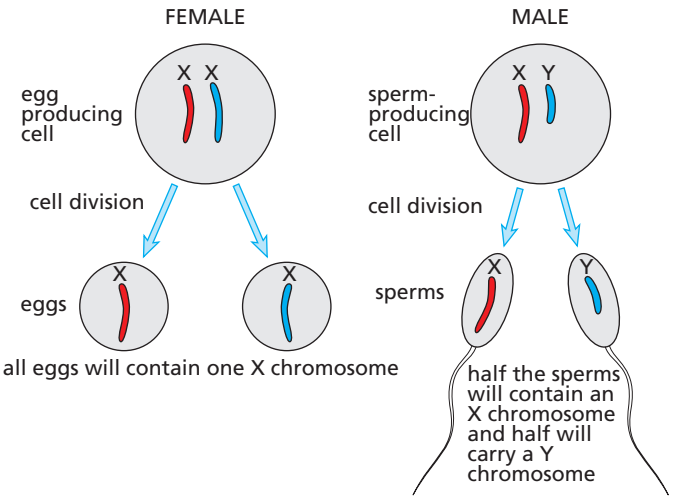
The genes that occupy corresponding positions on homologous chromosomes and control the same characteristic are called alleles. The word allele comes from *allelomorph*, which means *alternative form*. For example, there are two alternative forms of a gene for eye colour. One allele produces brown eyes and one allele produces blue eyes.

There are often more than two alleles of a gene. The human ABO blood groups are controlled by three alleles, though only two of these can be present in one **genotype**.

The inheritance of sex

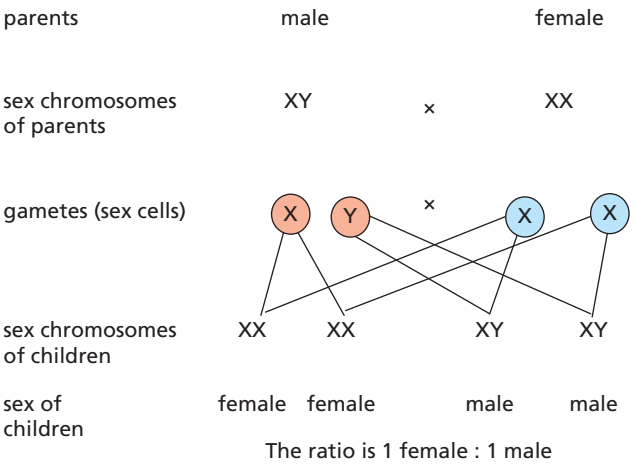
The pair of chromosomes called the sex chromosomes controls whether you are a male or female. In females, the two sex chromosomes, called the X chromosomes, are the same size as each other. In males, the two sex chromosomes are of different sizes. One corresponds to the female sex chromosomes and is called the X chromosome. The other is smaller and is called the Y chromosome. So the female cells contain **XX** and male cells contain **XY**.

A process takes place in the female's ovary that makes gametes (sex cells). These have half the normal number of chromosomes. During the process, each egg cell receives one of the X chromosomes, so all the egg cells are the same for this. The same process in the male's testes results in 50% of the sperms getting an X chromosome and 50% getting a Y chromosome (Figure 17.18). If an X sperm fertilises the egg cell, the zygote will be XX and will grow into a girl. If a Y sperm fertilises the egg cell, the zygote will be XY and will develop into a boy. There is an equal chance of an X or Y chromosome fertilising an egg cell, so the numbers of female and male babies born are roughly the same.



▲ **Figure 17.18** Determination of sex. **Note:** Only the X and Y chromosomes are shown

Figure 17.19 shows how sex is inherited.



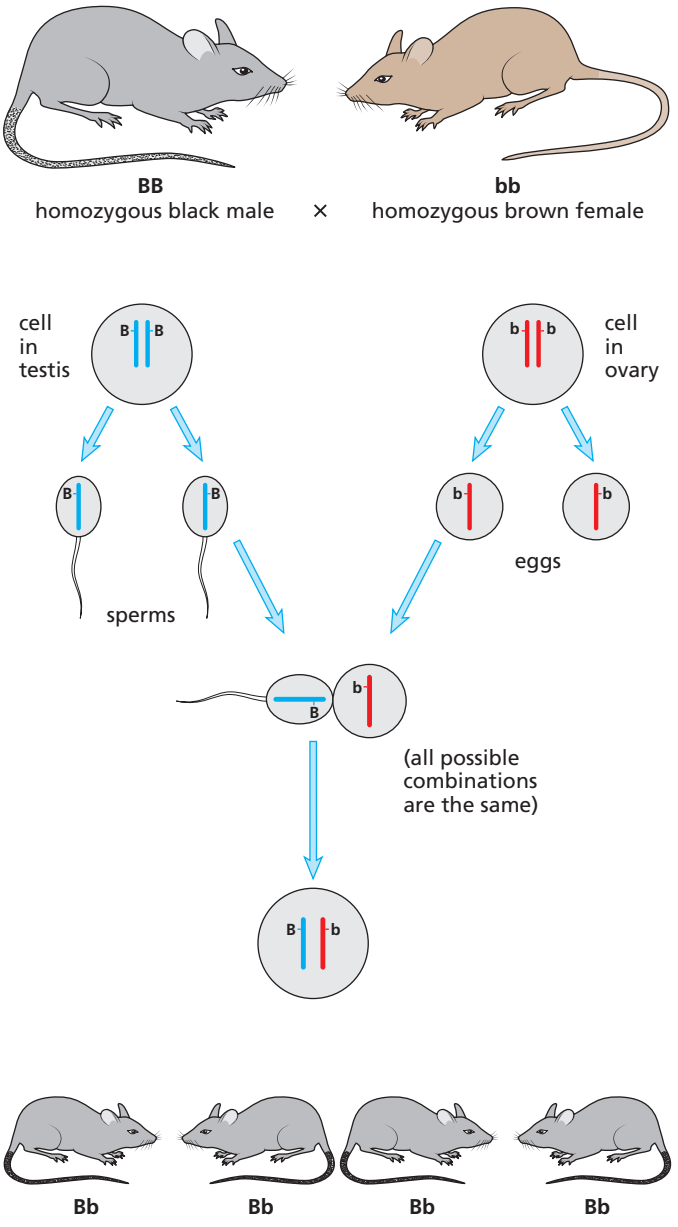
▲ **Figure 17.19** Determination of sex

The three to one ratio

The result of a mating between a true-breeding (homozygous) black mouse (**BB**) and a true-breeding (homozygous) brown mouse (**bb**) is shown in Figure 17.20(a). The example is simplified because it only shows one pair of the 20 pairs of mouse chromosomes and only one pair of alleles on the chromosomes.

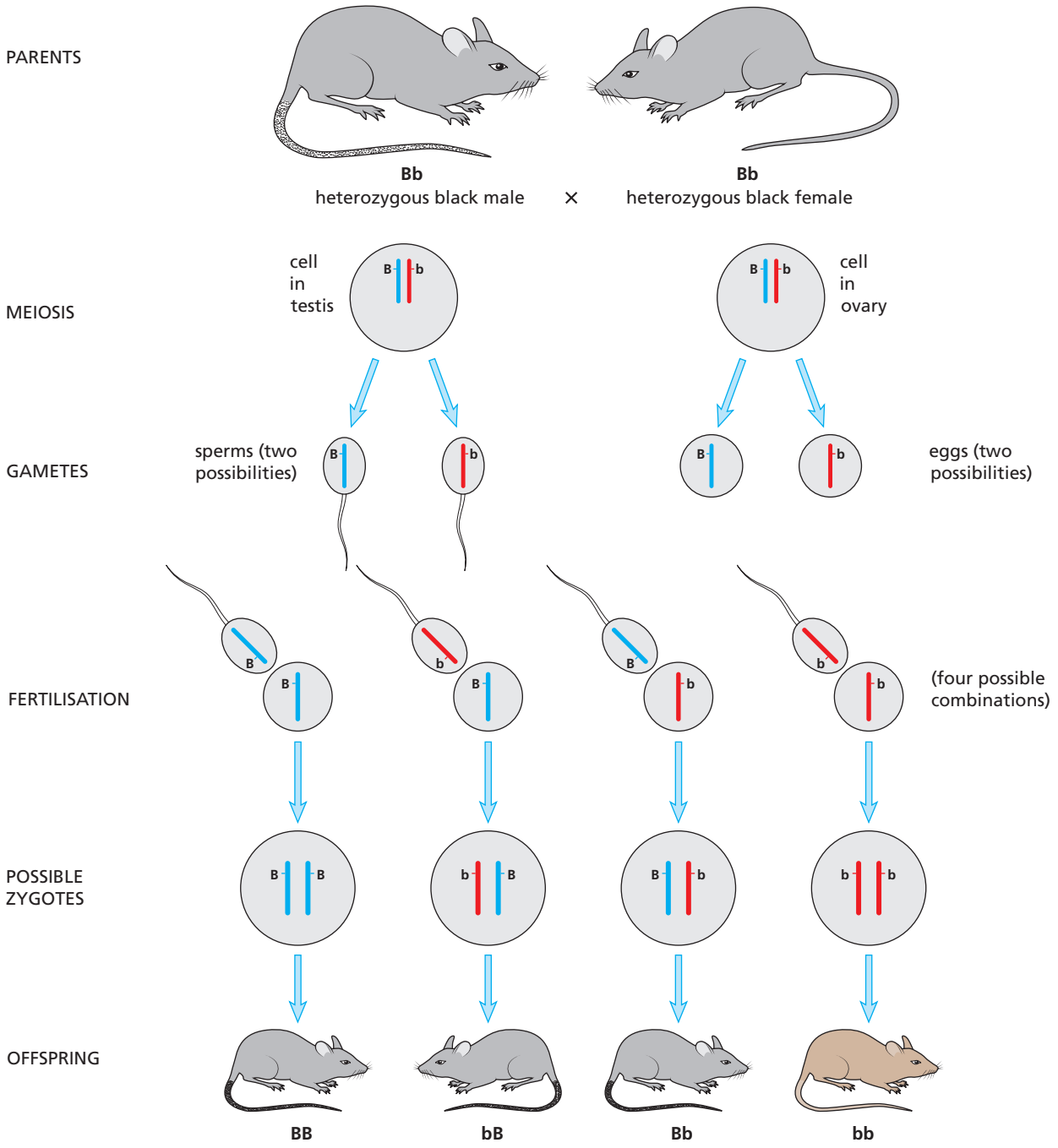
Because black is dominant to brown, all the offspring from this mating will be black phenotypes; they all receive the dominant allele for black fur from the father. Their genotypes, however, will be **Bb** because they all receive the recessive **b** allele from the mother. They are heterozygous for coat colour. The offspring resulting from this first mating are called the F_1 generation.

Figure 17.20(b) shows what happens when these heterozygous, F_1 black mice are mated together to produce what is called the F_2 generation. Each sperm or egg cell can contain only one of the alleles for coat colour, either **B** or **b**. So, there are two kinds of sperm cell, one kind with the **B** allele and one kind with the **b** allele. There are also two kinds of egg cell with either **B** or **b** alleles. When fertilisation occurs, there is no way of telling whether a **b** or a **B** sperm will fertilise a **B** or **b** egg cell, so we must look at all the possible combinations as follows:



(a) all the F_1 generation are heterozygous black

▲ **Figure 17.20** Inheritance of coat colour in mice



(b) the probable ratio of coat colours in the F_2 generation is 3 black : 1 brown

▲ **Figure 17.20** Inheritance of coat colour in mice (continued)

- A **b** sperm fertilises a **B** egg cell. Result: **bB** zygote.
- A **b** sperm fertilises a **b** egg cell. Result: **bb** zygote.
- A **B** sperm fertilises a **B** egg cell. Result: **BB** zygote.
- A **B** sperm fertilises a **b** egg cell. Result: **Bb** zygote.

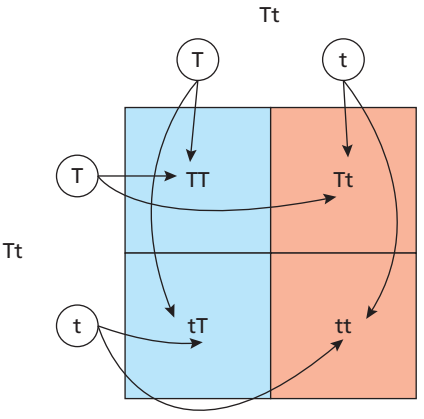
There is no difference between **bB** and **Bb**, so there are three possible genotypes in the offspring – **BB**, **Bb** and **bb.** There are only two phenotypes – black (**BB** or **Bb**) and brown (**bb**). So, according to the laws of chance, we would expect three black baby mice and one brown. Mice usually have more than four offspring and what we really expect is that the ratio (proportion) of black to brown will be close to 3:1.

If the mouse had 13 babies, you might expect nine black and four brown, or eight black and five brown.

Even if she had 16 babies you would not expect to find exactly 12 black and four brown because whether a **B** or **b** sperm fertilises a **B** or **b** egg cell is a matter of chance. If you spun ten coins you would not expect to get exactly five heads and five tails. You would not be surprised at six heads and four tails or even seven heads and three tails. In the same way, we would not be surprised at 14 black and two brown mice in a litter of 16. So you can see that observed ratios often differ from expected ratios, especially when there are small numbers of offspring.

To decide whether there really is a 3:1 ratio we need a lot of results. These may come either from breeding the same pair of mice together for a year or so to produce many litters, or from mating 20 black and 20 brown mice, crossing the offspring and adding up the number of black and brown babies in the F_2 families.

When working out the results of a genetic cross it is useful to display the outcomes in a **Punnett square** (Figure 17.21). This is a box divided into four compartments. The two boxes along the top are labelled with the genotypes of the gametes of one parent. The genotypes are circled to show they are gametes. The parent's genotype is written above the gametes. The boxes down the left-hand side are labelled with the genotypes of the gametes of the other parent. The parent's genotype is written to the left. The genotypes of the offspring can then be predicted by completing the four boxes, as shown. In this example, two heterozygous tall organisms (**Tt**) are the parents. The genotypes of the offspring are **TT**, **Tt**, **tT** and **tt**. We know that the allele **T** is dominant because the parents are tall, although they carry both tall and dwarf alleles. So, the phenotypes of the offspring will be three tall to one dwarf.



▲ **Figure 17.21** Using a Punnett square to predict the outcomes of a genetic cross

Worked example

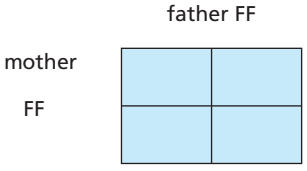
Use Punnett squares to work out the chances of inheriting cystic fibrosis, being a carrier and being healthy. State the answers as percentages and ratios.

Try using the following genotypes of the parents:

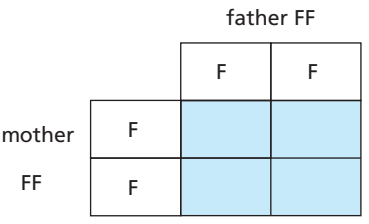
1. two healthy parents (both FF)
2. one parent who is a carrier for cystic fibrosis (Ff) and the other parent who is healthy (FF)
3. both parents who are carriers (Ff)
4. one parent is a carrier (Ff) and the other has the condition (ff).

Answer for situation 1.

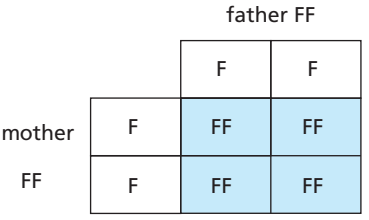
First, draw a square and divide it into four compartments. Label two sides of the square with the parents and their genotypes.



Next, write the genotypes of the gametes.



Now fill in the genotypes of the children in the four boxes in the Punnett square.



Finally, state the phenotypes of the children with the percentages and ratios.

In this case 100% of the children are FF, with a ratio of 1:0, so they will all be healthy.

Tasks

1 In a family there are two children who both have cystic fibrosis. Neither of their parents show the symptoms of the disorder.
   a Using a Punnett square, show how this is possible.
   b What is the ratio of
      i) phenotypes for this cross
      ii) genotypes for this cross?

2 A father has cystic fibrosis and his wife is a carrier of the disorder. They have children.
   a State the genotypes of the parents.
   b What are the chances of the children inheriting this disorder? Use a Punnett square and state your answers as
      i) percentages
      ii) ratios.

Test yourself

7 Some plants occur in one of two sizes, tall or dwarf. This characteristic is controlled by one pair of genes. Tallness is dominant to shortness. Choose suitable letters for the gene pair.

8 Use the words homozygous, heterozygous, dominant and recessive (where suitable) to describe the following allele combinations: **Aa**, **AA**, **aa**.

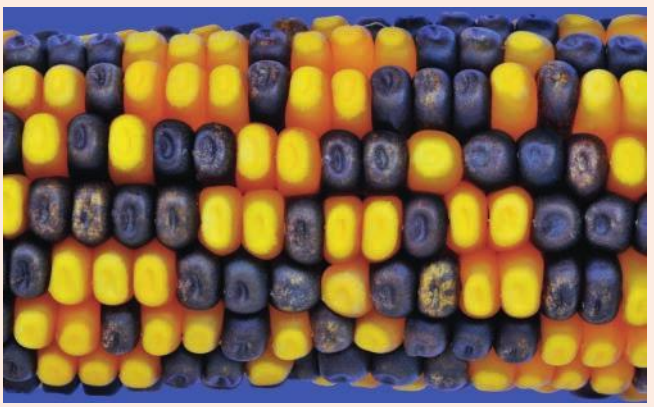
9 Study the photograph of varieties of maize cobs in Figure 17.22.
   a Count the number of light and dark grains on maize cob A and B.
   b Calculate the ratio of light to dark grains on each cob.
   c i) Based on the evidence in cob A, suggest which colour is dominant.
      ii) Choose letters to represent the colours of the grains.
   d Using these letters, suggest the genotypes of the parents of
      i) cob A
      ii) cob B.
   e State the phenotypes of the parents of each cob.

10 A husband and wife have four girls, but no boys. Explain why this does not mean that the husband produces only X sperms.

11 State which sex chromosome determines the sex of a baby. Explain your answer.

12 Use a diagram to show how the sex of a baby is determined.

Maize cob A



Maize cob B

▲ **Figure 17.22** Varieties of maize cobs

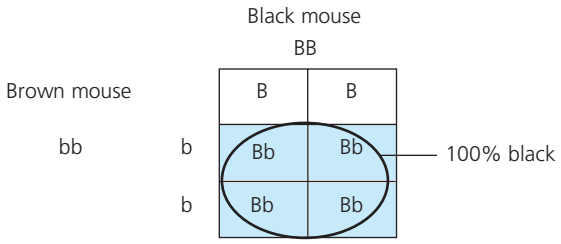
1:1 phenotypic ratio

A black mouse could have either the **BB** or the **Bb** genotype. One way to find out the genotype is to cross the black mouse with a known homozygous recessive mouse, **bb**. The **bb** mouse will produce gametes with only the recessive **b** allele. A black homozygote, **BB**, will produce only **B** gametes.

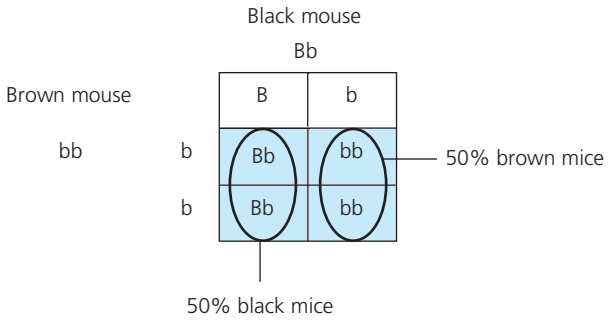
So, if the black mouse is **BB**, all the offspring from the cross will be black heterozygotes, **Bb**.

Half the gametes from a black **Bb** mouse would carry the **B** allele and half would have the **b** allele. So, if the black mouse is **Bb**, half of the offspring from the cross will, on average, be brown homozygotes, **bb**, and half will be black heterozygotes, **Bb**.

BB x bb



Bb x bb



Codominance

Key definitions

Codominance is a situation in which both alleles in heterozygous organisms contribute to the phenotype.

If both genes of an allelomorphic pair produce their effects in an individual (i.e. neither allele is dominant to the other) the alleles are said to be codominant.

The inheritance of the human ABO blood groups is an example of codominance. In the ABO system, there are four phenotypic blood groups, A, B, AB and O. The alleles for groups A and B are codominant. If a person inherits alleles for group A and group B, his or her red blood cells will carry both antigen A and antigen B.

However, the alleles for groups A and B are both completely dominant to the allele for group O. (Group O people have neither A nor B antigens on their red blood cells.)

Table 17.1 shows the genotypes and phenotypes for the ABO blood groups. (**Note:** The allele for group O is sometimes represented as I° and sometimes as i.)

▼ **Table 17.1** The ABO blood groups

Genotype	Blood group (phenotype)
I^AI^A or I^Ai	A
I^BI^B or I^Bi	B
I^AI^B	AB
ii	O

Since the alleles for groups A and B are dominant to that for group O, a group A person could have the genotype I^AI^A or I^Ai. Similarly, a group B person could be I^BI^B or I^Bi. There are no alternative genotypes for groups AB and O.

Inheritance of blood group O

Blood group O can be inherited even though neither parent shows this phenotype.

Two parents have the groups A and B. The father is I^Ai and the mother is I^Bi (Figure 17.23).

Phenotypes of parents blood group A × blood group B

Genotypes of parents I^Ai × I^Bi

Gametes I^A i × I^B i

Punnett square

	I^A	i
I^B	I^AI^B	I^Bi
i	I^Ai	ii

F_1 genotypes I^Ai I^Bi I^AI^B ii

F_1 phenotypes A B AB O

Ratio 1 : 1 : 1 : 1

▲ **Figure 17.23** Inheritance of blood group O

Some plants show codominance with petal colour. For example, with the gene for flower colour in the geranium, the alleles are C^R (red) and C^W (white). The capital letter '**C**' has been chosen to represent colour. Pure-breeding (homozygous) flowers may be red (C^RC^R) or white (C^WC^W). If these are cross-pollinated, all the first filial (F_1) generation will be heterozygous (C^RC^W) and they are pink because both alleles have an effect on the phenotype.

Self-pollinating the pink (F_1) plants results in an unusual ratio in the next (F_2) generation of 1 red : 2 pink : 1 white.

Test yourself

13 The presence of hairs on the body of a species of fly is controlled by a single pair of alleles. When a pure-breeding fly with body hairs is crossed with a pure-breeding fly with a smooth body, all the offspring have hairy bodies.

a **i)** Choose appropriate symbols to represent the alleles of the parents.

ii) Use these symbols to show the genotypes of the parents.

b Use genetic diagrams to show

i) how the offspring have hairy bodies

ii) a cross which would produce offspring with hairy bodies and smooth bodies in the ratio 1:1.

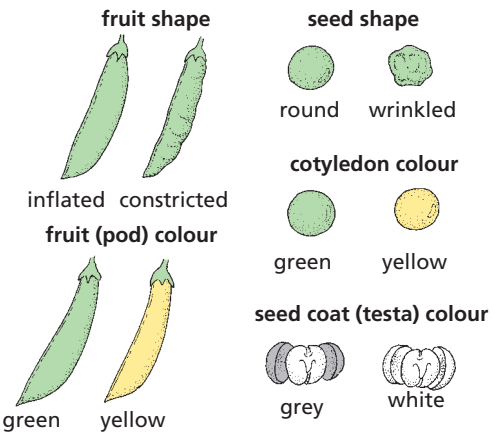
Going further

Ideas about heredity: Gregor Mendel (1822–1884)

Mendel was an Augustinian monk from the town of Brünn (now Brno) in Czechoslovakia (now the Czech Republic). He studied maths and science at the University of Vienna in order to teach at a local school.

He was the first scientist to make a systematic study of patterns of inheritance involving single characteristics. He did this by using varieties of the pea plant, *Pisum sativum*, which he grew in the monastery garden. He chose pea plants because they were self-pollinating (Chapter 16). Pollen from the anthers reached the stigma of the same flower even before the flower bud opened.

Mendel chose varieties of pea plant that had distinctive and contrasting characteristics, like green seeds vs yellow seeds, dwarf vs tall, round seeds vs wrinkled (Figure 17.24). He only used plants that were pure breeding.



▲ **Figure 17.24** Some of the characteristics investigated by Mendel

He then crossed pairs of the contrasting varieties. To do this he had to open the flower buds, remove the stamens and use them to dust pollen on the stigmas of the contrasting variety. The offspring of this cross he called the *first filial* generation, or F_1.

The first thing he noticed was that all the offspring of the F_1 cross showed the characteristic of only one of the parents. For example, tall plants crossed with dwarf plants only produced tall plants in the first generation.

Next, he allowed the plants of the F_1 generation to self-pollinate to produce a second filial generation, or F_2. Surprisingly, the dwarf characteristic that had, apparently, disappeared in the F_1 reappeared in the F_2. This characteristic had not, in fact, been lost but only hidden or inhibited in the F_1 to come back in the F_2. Mendel called the hidden feature *recessive* and the expressed feature *dominant*.

Also, it must be noted, the plants were all either tall or dwarf; there was nothing inbetween, which would have happened if the characteristics blended.

Mendel noticed that pollen from tall plants, transferred to the stigmas of short plants, produced the same result as transferring pollen from short plants to the stigmas of tall plants. This meant that male and female gametes both contributed to the observed characteristic.

When Mendel counted the number of contrasting offspring in the F_2, he found that they happened in the ratio of three dominant to one recessive. For example, of 1 064 F_2 plants from the tall × dwarf cross, 787 were tall and 277 dwarf, a ratio of 2.84:1. This F_2 ratio occurred in all Mendel's crosses, for example:

- round vs wrinkled seed 5 474:1850 = 2.96:1
- yellow vs green seed 6 022:2 001 = 3.01:1
- green vs yellow pod 428:152 = 2.82:1.

Two-thirds of the dominant tall F_2 plants did not breed true when self-pollinated but produced the 3:1 ratio of tall : dwarf. So, they were similar to the plants of the F_1 generation.

Mendel's symbols **A**, **Ab** and **b** seem to be shorthand for the types of plants he studied: **A** = true-breeding dominant, **b** = true-breeding recessive and **Ab** = the non-true-breeding hybrid. The letters represented the visible characteristics. Now, they represent the alleles responsible for producing the characteristic. For example, Mendel never refers to **AA** or **bb**, so he probably did not appreciate that each characteristic is represented twice in the somatic (body) cells but only once in the gametes.

When Mendel crossed plants each carrying two contrasting characteristics, he found that the characteristics turned up in the offspring independently of each other. For example, in a cross between a tall plant with green seeds and a dwarf plant with yellow seeds, some of the offspring were tall with yellow seeds and some dwarf with green seeds.

So, Mendel's work was descriptive and mathematical rather than explanatory. He showed that certain characteristics were inherited in a predictable way, that the gametes were the vehicles. These characteristics did not blend but kept their identity and could be inherited independently of each other. He also recognised dominant and recessive characteristics and found that the recessive characteristic did not disappear when it was in the presence of the dominant characteristic.

Mendel published his results in 1866 in *Transactions of the Brünn Natural History Society*. It did not have a wide circulation so not many people saw his work. The importance and significance of his findings were only appreciated when Mendel's work was rediscovered in 1900.

Scientists sometimes summarise Mendel's observations in the form of Mendel's laws.

- The first law (the law of segregation) states that 'Of a pair of contrasted characters only one can be represented in the gamete'.
- The second 'law' (the law of independent assortment) states that 'Each of a pair of contrasting characters may be combined with either of another pair'.

Mutations

Key definitions

Gene mutation is a random change in the base sequence of DNA.

Mutation is genetic change.

A **chromosome mutation** is a change in the chromosome number or structure.

A mutation is a spontaneous genetic change and the way new alleles are formed.

Many of the cat coat variations mentioned on page 307 may have arisen, in the first place, as mutations in a wild stock of cats. A recent variant produced by a mutation is the *rex* variety, in which the coat has curly hairs.

Many of our high-yielding crop plants have occurred as a result of mutations in which the whole chromosome set has been doubled.

A mutation may occur in a gene or a chromosome. In a gene mutation one or more genes may not be copied correctly. A chromosome mutation may result from the loss of part of a chromosome, or damage to it, during mitosis or meiosis. There can even be the gain of an extra chromosome, as in Down's syndrome (see page 303). A gene mutation may affect the protein that the gene codes for. An example of this is Sickle-cell anaemia (see page 302). In this case the protein coded for by the mutated gene is haemoglobin.

A sudden change in a gene or chromosome is likely to result in a faulty enzyme and will usually upset the complex reactions in the cells. So, most mutations are harmful to the organism.

Surprisingly, only about 3% of human DNA is made of genes. The rest consists of repeated sequences of nucleotides (the structural units of DNA) that do not code for proteins. This is sometimes called junk DNA, but that term only means that we do not know its function. If mutations happen in these non-coding sequences they are unlikely to have any effect on the organism.

Rarely, a gene or chromosome mutation produces a useful effect and this may contribute to the success of the organism (see 'Selection' later in this chapter).

If a mutation occurs in a gamete it will affect all the cells of the individual that develops from the zygote. So, the whole organism will be affected. If the mutation occurs in a somatic cell (body cell), it will affect only those cells produced from that cell dividing by mitosis.

So, a mutation in a gamete may result in a genetic disorder, for example, haemophilia or cystic fibrosis. Mutations in somatic (body) cells may give rise to cancers by stimulating uncontrolled cell division in the affected tissue. For example, skin cancer results from uncontrolled cell division in the basal layer of the skin.

A mutation may be as small as the substitution of one organic base for another in the DNA molecule, or as large as the breakage, loss or gain of a chromosome.

Mutations in bacteria

Mutations in bacteria often produce resistance to drugs. Bacterial cells reproduce very rapidly, perhaps as often as once every 20 minutes. As a result, a mutation, even if it occurs very rarely, is likely to appear in a large population of bacteria. If a population of bacteria containing one or two drug-resistant mutants is exposed to that drug, the non-resistant bacteria will be killed but the drug-resistant mutants will survive (see Figure 17.29). Mutant genes are inherited in the same way as normal genes, so when the surviving mutant bacteria reproduce, all their offspring will be resistant to the drug.

Mutations are quite rare events; perhaps only one in every 100 000 replications results in a mutation. Even so, they do occur naturally all the time.

Causes of increases in the rate of mutation

Substances, such as some chemicals and also **ionising radiation** can change DNA. Exposure to them increases the rate of mutation. Some of the substances in tobacco smoke, like tar, are mutagens, which can cause cancer.

Ionising radiation from X-rays and radioactive compounds, and ultraviolet radiation from sunlight, can increase the mutation rate. It is uncertain whether there is a minimum dose of radiation below which there is only a tiny risk. It is possible that repeated exposure to low doses of radiation is as harmful as one exposure to a high dose. Recently it has been discovered that light skinned people can develop skin cancer if they do not protect themselves from exposure to ultraviolet radiation from the Sun.

Generally, occasional exposure to natural and medical sources of radiation carries less risk than smoking cigarettes or driving a car, but it is sensible to keep exposure to a minimum.

Sources of genetic variation in populations

Genetic variation may be the result of mutations. In addition, meiosis, random mating and new combinations of genes in the zygote through random fertilisation are all sources of genetic variation in populations.

New combinations of genes

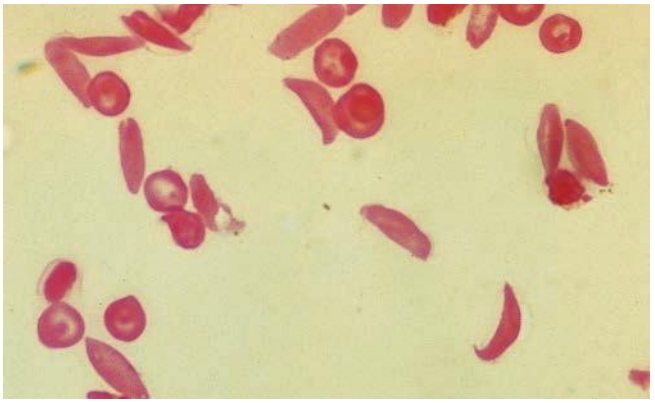
If a grey cat with long fur is mated with a black cat with short fur, the kittens will all be black with short fur. If these offspring are mated together, eventually the litters of kittens may include four varieties: black–short, black–long, grey–short and grey–long. Two of these are different from either of the parents.

Sickle-cell anaemia

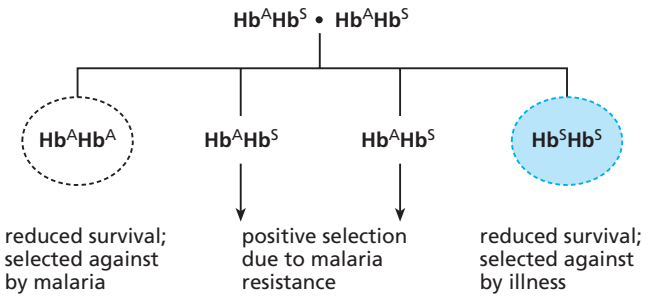
A person with sickle-cell disease has inherited both recessive alleles ($\mathbf{Hb^sHb^s}$) for defective haemoglobin. The distortion and destruction of the red blood cells, which occurs in low oxygen concentrations, leads to bouts of severe anaemia (Figure 17.25). In many African countries, sufferers have a reduced chance of reaching reproductive age and having a family. There is thus a selection pressure, which tends to remove the homozygous recessives from the population. In such a case, you might expect the harmful $\mathbf{Hb^s}$ allele to be selected out of the population altogether. However, the heterozygotes ($\mathbf{Hb^AHb^s}$) have virtually no symptoms of anaemia but do have the advantage that they are more resistant to malaria than the homozygotes $\mathbf{Hb^AHb^A}$. It appears that the malaria parasite is unable to invade and reproduce in the sickle cells.

The selection pressure of malaria, therefore, favours the heterozygotes over the homozygotes and the potentially harmful $\mathbf{Hb^s}$ allele is kept in the population (Figure 17.26).

When Africans migrate to countries where malaria does not occur, the selective advantage of the $\mathbf{Hb^s}$ allele is lost and the frequency of this allele in the population diminishes.



▲ **Figure 17.25** Sickle-cell anaemia (× 800). At low oxygen concentration the red blood cells become distorted



▲ **Figure 17.26** Selection in sickle-cell disease

With **sickle-cell anaemia**, the defective haemoglobin molecule differs from normal haemoglobin by only one amino acid (represented by a sequence of three bases), i.e. *valine* replaces *glutamic acid*. This could be the result of faulty replication at meiosis. When the relevant parental chromosome replicated at gamete formation, the DNA could have produced the triplet –CAT– (which specifies *valine*) instead of –CTT– (which specifies *glutamic acid*). In this case, a change of just one base (from A to T) makes a significant difference to the characteristics of the protein (haemoglobin).

Sickle-cell anaemia is an example of incomplete dominance. This term is sometimes taken to mean the same as 'codominance' but, strictly, it applies to a case where the effect of the recessive allele is not completely masked by the dominant allele.

If a person inherits both recessive alleles ($\mathbf{Hb^SHb^S}$) for sickle-cell haemoglobin, then he or she will exhibit signs of the disease, i.e. distortion of the red blood cells leading to severe bouts of anaemia.

A heterozygote ($\mathbf{Hb^AHb^S}$), however, will have a condition called 'sickle-cell trait'. Although there may be mild symptoms of anaemia, the condition is not serious or life-threatening. In this case, the normal haemoglobin allele ($\mathbf{Hb^A}$) is not completely dominant over the recessive ($\mathbf{Hb^S}$) allele.

Down's syndrome

Down's syndrome is a form of mental and physical disability, which results from a chromosome mutation. During the process of meiosis which produces an egg cell, one of the chromosomes (chromosome 21) fails to separate from its homologous partner, a process known as non-disjunction. As a result, the egg cell carries 24 chromosomes instead of 23, and the resulting zygote has 47 instead of the normal 46 chromosomes. The risk of having a baby with Down's syndrome increases as the mother gets older.

Test yourself

14 The diagram shows six bases coding for two amino acids in part of a gene.
- A - T - G - C - A - G -

When copied, there was a slight change in the bases.
- A - C - G - C - A - G -

a Name the process that causes a change in the structure of DNA.

b Suggest why this change may affect the organism in which it has occurred.

Selection

FOCUS POINTS

- ★ What is natural selection?
- ★ What is adaptation?
- ★ What is an example of natural selection?
- ★ What is artificial selection?
- ★ How is selective breeding by artificial selection carried out over many generations to improve crop plants and domesticated animals?

Natural selection

Theories of evolution have been put forward in various forms for hundreds of years. In 1858, Charles Darwin and Alfred Russel Wallace published a theory of evolution by natural selection, which is still an acceptable theory today.

The theory of evolution by natural selection states that:

- Individuals within a population of a species are all slightly different from each other (Figure 17.27). These differences are called variations.
- If the climate or **food supply** changes, individuals with some of these variations may be more able to survive than others. For example, a variety of animal that could eat the leaves of shrubs as well as grass would be more likely to survive a drought than one that only fed on grass.
- If one variety lives longer than others, it is also likely to leave behind more offspring. A mouse that lives for 12 months may have ten litters of five babies (50 in total). A mouse that lives for 6 months may have only five litters of five babies (25 in total).
- If some of the offspring inherit alleles responsible for the variation that helped the parent survive better, they will also live longer and have more offspring.
- In time, this particular variety will outnumber and finally replace the original variety.

This is sometimes called *the survival of the fittest*. However, in this case, fitness does not mean good health but suggests that the organism is well fitted to the conditions in which it lives.

▲ **Figure 17.27** Variation. The garden tiger moths in this picture are all from the same family. There is a lot of variation in the pattern on the wings

Thomas Malthus, in 1798, suggested that the increase in the size of the human population would overtake the rate of food production. He predicted that the number of people would eventually be regulated by famine, disease and war. When Darwin read the Malthus essay, he applied its principles to other populations of living organisms.

He observed that animals and plants produce far more offspring than can possibly survive to maturity and he concluded that there must be a *struggle for survival*.

For example, if a pair of rabbits had eight offspring that grew up. They formed four pairs and eventually had eight offspring per pair. In four

generations the number of rabbits stemming from the original pair would be 512 (i.e. 2 → 8 → 32 → 128 → 512). The population of rabbits, however, remains roughly constant. So, many of the offspring in each generation must have died before they reached reproductive age.

Competition and selection

There will be competition between members of the rabbit population for food, burrows and mates. If food is limited, space is short and the number of potential mates limited, then only the healthiest, most active, most fertile and well-adapted rabbits will survive and breed.

The competition does not have to involve direct conflict. The best adapted rabbits may be able to run faster from predators, digest their food more efficiently, have larger litters, or grow coats that camouflage them better or more effectively reduce heat losses. These rabbits will survive longer and leave more offspring. If the offspring inherit the advantageous characteristics of their parents, they may produce a new race of faster, different coloured, thicker furred and more fertile rabbits, which gradually replace the original, less well-adapted varieties. The new variations are said to have survival value.

This is natural selection; the better adapted varieties are selected by the pressures of the environment.

For natural selection to be effective, the variations must be heritable. Variations that are not heritable are of no value in natural selection. Training may give athletes more efficient muscles, but this characteristic will not be passed on to their children.

The peppered moth

A possible example of natural selection is provided by a species of moth called the peppered moth, found in Great Britain. The common form is speckled but there is also a variety that is black. The black variety was rare in 1850, but by 1895 in one industrial area of England its numbers had increased to 98% of the population of peppered moths. Observation showed that the light variety had better camouflage than the dark variety when they rested on tree trunks covered with lichens (Figure 17.28). In the industrial area of England, pollution had killed the lichens and darkened the tree trunks with soot. In this area the dark variety was the better camouflaged (hidden) of the two and was not predated by birds. So, the dark variety survived better, left more offspring and nearly replaced the light form.

The selection pressure, in this case, was presumed to be mainly **predation** by birds. The adaptive variation that produced the selective advantage was the dark colour.

Although this is an attractive and likely hypothesis of how natural selection could occur, some of the evidence does not support the hypothesis or has been challenged.

For example, the moths settle most often on the underside of branches rather than visibly on tree trunks, as in Figure 17.28. Also, in several unpolluted areas the dark form is quite common, for example, 80% in an agricultural region with no heavy industry. Research is continuing in order to test the hypothesis.

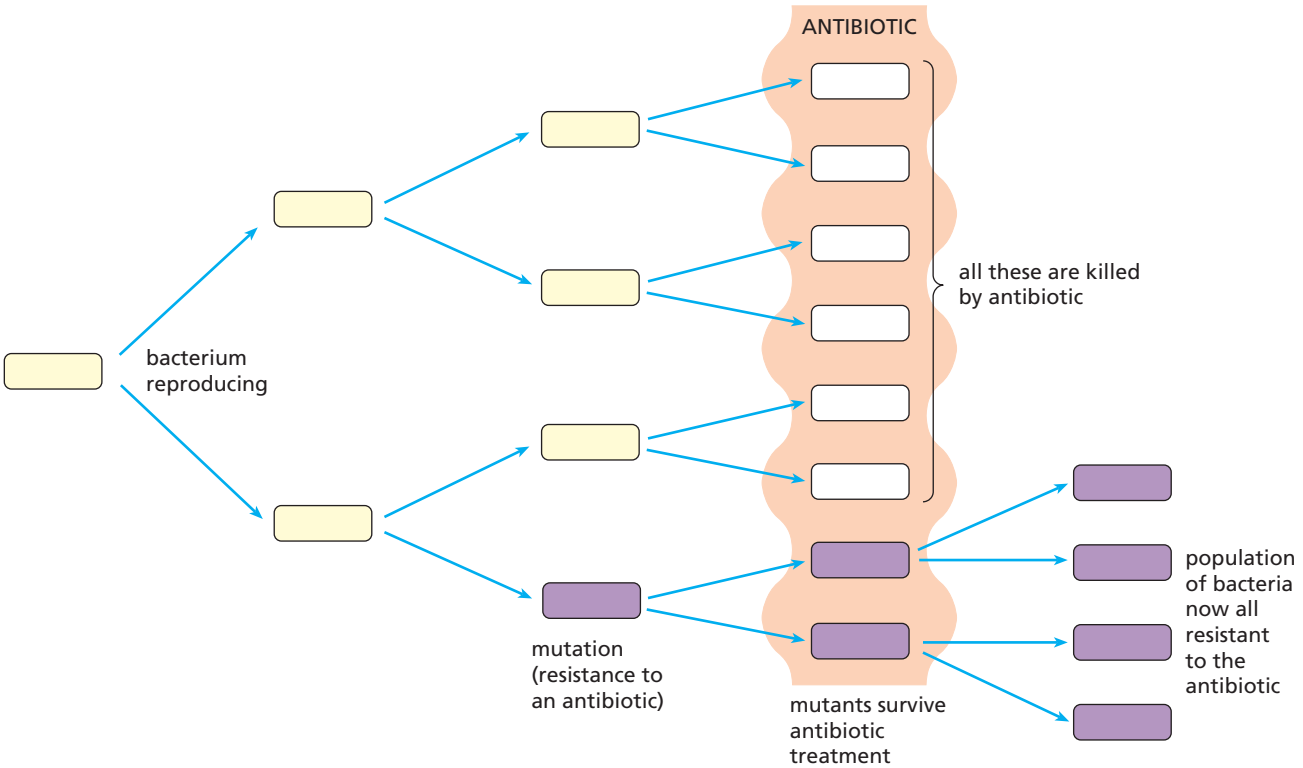
(a) (b) (c) (d)

▲ **Figure 17.28** Selection for varieties of the peppered moth

Adaptation

Slow changes in the environment result in adaptations in a population to cope with the changes. These adaptations are the result of natural selection, by which populations become more suited to their environment over many generations. This is a possible mechanism for evolution. Evolution can be described as the change in adaptive features of a population over time as a result of natural selection.

A course of antibiotics is given to a patient to destroy bacteria. If the patient does not complete the course of antibiotics, some of the bacteria will not be killed. However, they will have been exposed to the drug. Some of the survivors may be drug-resistant mutants. When they reproduce, all their offspring will have the drug resistance, so the antibiotic will become less effective (Figure 17.29).



▲ **Figure 17.29** Mutation in bacteria can lead to drug resistance

MRSA (methicillin-resistant *Staphylococcus aureus*) is one type of bacteria that has developed resistance to several widely used antibiotics. These types of bacteria are sometimes called *superbugs* because they are so difficult to treat. *Staphylococcus aureus* is very common and lives harmlessly on the skin, nose and throat, sometimes causing mild infections. It becomes dangerous if there is a break in the skin. Then, the bacterium can get into the bloodstream to infect internal organs and cause blood poisoning. This can happen in hospitals with infection during operations, especially if hygiene precautions are not good enough.

Development of strains of antibiotic-resistant bacteria

If a population of bacteria containing one or two drug-resistant mutants is subjected to that particular drug, the non-resistant bacteria will be killed but the drug-resistant mutants survive (Figure 17.29). Mutant genes are inherited in the same way as normal genes so, when the surviving mutant bacteria reproduce, all their offspring will be resistant to the drug. This is an example of natural selection.

Artificial selection (selective breeding)

The process of selective breeding involves humans choosing individuals with desirable features. These individuals are then cross-bred to produce the next generation. Offspring with the most desirable features are chosen to continue the breeding programme and the process is repeated over several generations.

Human communities use this form of selection when they breed plants and animals for specific characteristics. The range of varieties of cat that you see today have been produced by selecting individuals with pointed ears, fur colour or length, or even no tail, etc. One of the kittens in a litter might vary from the others by having very pointed ears. When mature, this kitten is allowed to breed. Another very pointed-eared variant is selected from the offspring for the next breeding stock. The process is repeated until the desired or *fashionable* ear shape is established in a pure-breeding population (Figure 17.30).

▲ **Figure 17.30** Selective breeding. The Siamese cat, produced by selective breeding over many years

More important are the breeding programmes to improve agricultural livestock or crop plants. Plant-breeders will select varieties for their high yield and resistance to fungal diseases. Seeds from the tomato plants with the largest fruits are collected and planted next year. In the next generation, the tomato plants with the largest fruits are again selected. Their seeds are collected and planted. Eventually it is possible to produce a true-breeding variety of tomato plant that forms large fruits. Figure 17.31 shows the result of this type of selective breeding. The same technique can be used for selecting other desirable qualities, like flavour and disease resistance.

▲ **Figure 17.31** Selective breeding in tomatoes. Different breeding programmes have selected genes for fruit size, colour and shape. Similar processes have resulted in most of our cultivated plants and domesticated animals

Similar methods can be applied to farm animals. Desirable characteristics, such as high milk yield and resistance to disease, may be combined. Stock-breeders will select calves from cows that give large quantities of milk. These calves will be used as breeding stock to build a herd of cows that all produce high yields of milk. A characteristic like milk yield is probably under the control of many genes. At each stage of selective breeding the farmer is effectively keeping the beneficial genes and discarding the less useful genes from his or her animals.

Selective breeding in farm stock can be slow and expensive because the animals often have small numbers of offspring and breed only once a year.

Another disadvantage of selective breeding is that the whole set of genes is transferred. As well as the desirable genes, there may be genes that, in a homozygous condition, would be harmful. It is known that **artificial selection** repeated over several generations tends to reduce the fitness of the new variety.

A long-term disadvantage of selective breeding is the loss of variability. By removing all the offspring that do not have the desired characteristics, many genes are lost from the population. In the future, when new combinations of genes are required, some of the potentially useful ones may no longer be available.

In attempting to introduce characteristics such as salt tolerance or resistance to disease or drought in plants, the geneticist goes back to wild varieties, as shown in Figure 17.32. However, with the current rate of extinction, this source of genetic material is declining.

In the natural world, reduction of variability could lead to local extinction if the population is unable to adapt, by natural selection, to changing conditions.

▲ **Figure 17.32** The genetics of bread wheat. A primitive wheat (a) was crossed with a wild grass (b) to produce a better-yielding hybrid wheat (c). The hybrid wheat (c) was crossed with another wild grass (d) to produce one of the varieties of wheat (e), which is used for making flour and bread

Comparing natural and artificial selection

Natural selection occurs in groups of living organisms by the best adapted organisms passing on genes to the next generation, without human interference. Those with genes that provide an advantage to cope with changes in environmental conditions, for example, are more likely to survive. Others will die before they can breed and pass on their genes. However, there is still variation in the population.

Artificial selection is used by humans to produce varieties of animals and plants that have an increased economic importance. It is considered a safe way of developing new strains of organisms, compared with, for example, genetic modification (see Chapter 18), and is a much faster process than natural selection. However, artificial selection removes variation from a population, leaving it prone to disease and unable to cope with changes in environmental conditions. So, potentially, artificial selection puts a species at risk of extinction.

Test yourself

15 Suggest some good characteristics that an animal-breeder might try to combine in sheep by mating different varieties together.

16 A variety of barley has a good ear of seed but has a long stalk and is easily blown over. Another variety has a short, sturdy stalk but a poor ear of seed. Suggest a breeding programme to obtain and select a new variety that combines both of the useful characteristics. Choose letters to represent the genes and show the genotypes of the parent plants and their offspring.

17 Explain how the development of strains of antibiotic-resistant bacteria is an example of natural selection.

Revision checklist

After studying Chapter 17 you should know and understand the following:

Variation

- ✔ Variation is the differences between individuals of the same species.
- ✔ Continuous variation results in a range of phenotypes between two extremes, for example, height in humans.
- ✔ Discontinuous variation results in a limited number of phenotypes with no intermediates, for example, tongue rolling.
- ✔ Discontinuous variation is usually caused by a single gene.
- ✔ Discontinuous variations cannot be changed by the environment.
- ✔ Continuous variations are usually controlled by a number of genes affecting the same characteristic and can be influenced by the environment.
- ✔ Mutation is genetic change.

- ✔ A mutation is the way in which new alleles are formed.
- ✔ Gene mutation is a random change in the base sequence of DNA.
- ✔ Mutation, meiosis, random mating and random fertilisation are sources of genetic variation in populations.
- ✔ A chromosome mutation is a change in the chromosome number or structure.
- ✔ Increases in the rate of mutation can be caused by ionising radiation and some chemicals.

DNA

- ✔ Chromosomes contain DNA, carrying information in the form of genes.
- ✔ A gene is a length of DNA that codes for a protein.
- ✔ An allele is an alternative form of a gene.
- ✔ Sex, in humans, is determined by the X and Y chromosomes. Males are XY; females are XX.
- ✔ DNA is made up of two stranded chains of nucleotides. Each nucleotide is made of a five carbon sugar, phosphate and a base. The strands are joined by bonds between the bases.
- ✔ Sequences of bases control production of the amino acids that make up a specific protein.
- ✔ Different sequences of amino acids give different shapes to protein molecules.
- ✔ DNA controls cell function by controlling the production of proteins.
- ✔ The process of making proteins involves mRNA and ribosomes.
- ✔ All body cells in an organism contain the same genes, but many genes in a particular cell are not expressed because the cell only makes the specific proteins it needs.

Inheritance

- ✔ Inheritance is the transmission of genetic information from generation to generation.
- ✔ The genotype of an organism is its genetic make-up.
- ✔ The phenotype of an organism is its observable features.
- ✔ Homozygous means having two identical alleles of a particular gene. Two identical homozygous individuals that breed together will be pure-breeding.
- ✔ Heterozygous means having two different alleles of a particular gene. A heterozygous individual will not be pure-breeding.
- ✔ A dominant allele is one that is expressed if it is present in the genotype.
- ✔ A recessive allele is one that is only expressed when there is no dominant allele of the gene present in the genotype.
- ✔ Genetic diagrams are used to predict the results of monohybrid crosses and calculate phenotypic ratios.
- ✔ Punnett squares can be used in crosses to work out and show the possible different genotypes.
- ✔ In some cases, neither one of a pair of alleles is fully dominant over the other. This is called codominance.
- ✔ The inheritance of ABO blood groups is an example of codominance.
- ✔ Genetic diagrams can be used to predict the results of monohybrid crosses involving codominance.

Selection

- ✔ Some members of a species may have variations that enable them to compete more effectively.
- ✔ These variants will live longer and leave more offspring.
- ✔ If the beneficial variations are inherited, the offspring will also survive longer.
- ✔ The new varieties may gradually replace the older varieties.
- ✔ Natural selection involves the elimination of less well-adapted varieties by environmental pressures.
- ✔ The inherited features of a population can evolve over time as a result of natural selection.
- ✔ The development of strains of antibiotic-resistant bacteria is an example of natural selection.
- ✔ Selective breeding is used to improve commercially useful plants and animals.

Exam-style questions

1 The height of a variety of pea plant is controlled by a single pair of alleles. When a pure-breeding tall plant is crossed with a pure-breeding dwarf plant, all the offspring are tall.
Use a genetic diagram or Punnett square to show a cross involving the peas described above that would produce tall offspring and dwarf offspring in a ratio of 1:1. [5]

2 **a** Distinguish between the terms
i) *gene* and *allele* [2]
ii) *dominant* and *recessive* [2]
iii) *phenotype* and *genotype*. [2]

3 A plant has two varieties, one with red petals and one with white petals. When these two varieties are cross-pollinated, all the offspring have red petals. Which allele is dominant?
Choose suitable letters to represent the two alleles. [2]

4 The allele for red hair is recessive to the allele for black hair.
a State what colour hair a child will have if he inherits an allele for red hair from his mother and an allele for black hair from his father. [1]
b State the genotype of the mother. [1]
c Is it possible for parents who both have black hair to have a child with red hair? Explain your answer. [1]

5 Using a suitable **named** example, explain how the following phenotypic ratios can be obtained from a genetic cross in a plant.
a 1:1
b 3:1 [8]

6 **a** Define the term *codominance*. [2]
b **i)** Use a genetic diagram or Punnett square to explain how a woman with blood group A and a man with blood group B can have a child with blood group O. [6]
ii) What is the chance of this man and woman having a child with blood group O? [1]

7 Pears from the same tree were collected and measured. The ranges in length of a sample of 150 of the pears are shown in the table.

range in length/cm	number of pears	range in length/cm	number of pears
Under 10.0	1	13.0–13.4	24
10.0–10.4	3	13.5–13.9	20
10.5–10.9	5	14.0–14.4	17
11.0–11.4	7	14.5–14.9	14
11.5–11.9	9	15.0–15.4	9
12.0–12.4	13	15.5–15.9	7
12.5–12.9	19	16.0 and over	2

a Plot a graph of the range in length against number of pears. [4]
b **i)** What is the commonest range in lengths of the pears? [1]
ii) Name the type of variation shown by the data. [1]
iii) Suggest **three** environmental factors that could be responsible for the variation in the pears. [3]
c The flowers from which the pears formed were pollinated by insects.
Explain why the seeds in the pears did not all have the same genotype. [2]

8 **a** **i)** Define the term *mutation*. [1]
ii) State **three** factors that can cause an increase in mutation. [3]
b **i)** What type of variation is shown by human blood groups? [1]
ii) State what type of graph would be suitable to display data about the frequencies of blood groups in a population. [1]

9 One variety of barley has a short stem and large seeds. Another variety has a long stem and small seeds. When they are cross-pollinated, the offspring are all short-stemmed with small seeds. These were then self-pollinated.

a List the four varieties that could be produced. [1]

b Which of these are different from either of the parent plants? [2]

10 a Outline the structure of DNA. [3]

b Describe how the bases are arranged in a DNA molecule. [3]

18 Biotechnology and genetic modification

Focus

Earlier in this book we looked at how cells grow and divide to form new cells, and what information is stored in them. The information is encoded in DNA in the form of genes and scientists have learned how to read this code. This chapter investigates how scientists can change or add to the genetic code to give the organism different qualities. How can our food crops be improved now that we have this new knowledge and skills? Is it safe to change the DNA of a living thing? Genetic modification raises a number of ethical issues which we will consider here.

Biotechnology

FOCUS POINTS

- ★ How and why is yeast important in biotechnology?
- ★ How are bacteria useful in biotechnology and genetic modification?
- ★ Why are bacteria useful in biotechnology and genetic modification?
- ★ How are fermenters used for large-scale production of biotechnology products?
- ★ What conditions need to be controlled in a fermenter?
- ★ How are enzymes used in biotechnology?
- ★ What is the role of anaerobic respiration in yeast during the production of biofuels and in bread-making?
- ★ What is the role of pectinase in fruit juice production?
- ★ What is the role of biological washing powders that contain enzymes?
- ★ What is the role of lactase in lactose-free milk production?

Biotechnology is the application of biological organisms, systems or processes to manufacturing and service industries. **Genetic modification** involves the transfer of genes from one organism to (usually) an unrelated species.

Both processes often make use of bacteria because they can make complex molecules, for example, proteins, and have a rapid reproduction rate.

Use of bacteria in biotechnology and genetic modification

Bacteria are useful in biotechnology and genetic modification because they can be grown and manipulated without raising ethical concerns. They have a genetic code that is the same as all other organisms, so scientists can transfer genes from other animals or plants into bacterial DNA. They are especially useful because they multiply so fast (up to three times an hour).

Bacterial DNA is in the form of a circular strand and also small circular pieces called plasmids.

Scientists have developed techniques to cut open these plasmids and insert sections of DNA from other organisms into them. When the bacterium divides, the DNA in the modified plasmid is copied, including the extra DNA. This may contain a gene to make a protein like insulin. The bacteria with this gene can now make specific complex molecules like the protein insulin. This can be extracted and used as a medicine to treat diabetes.

Although biotechnology appears to be one of the latest discoveries in science, we have been making use of it for hundreds of years. The baking of bread, wine-making, the brewing of beer and the production of cheese all depend on fermentation processes brought about by yeasts, other fungi and bacteria, or enzymes from these organisms.

Antibiotics, like penicillin, are produced by mould fungi or bacteria. The production of industrial chemicals like citric acid or lactic acid needs bacteria or fungi to bring about essential chemical changes.

Sewage disposal depends on bacteria in the filter beds to form the basis of the **food chain** that purifies the effluent.

Biotechnology is not only concerned with the use of microorganisms. Cell cultures and enzymes are also involved in modern developments.

Fermentation

Fermentation includes a wide range of reactions under the influence of enzymes or microorganisms such as yeast. In Chapter 10, the anaerobic respiration of glucose to ethanol was described. This is a form of fermentation.

Microorganisms involved in fermentation are using the chemical reaction to release energy, which they need for their living processes.

Ethanol

Ethanol (alcohol) can be produced from fermented sugar or spare grain by yeast. This could replace, or at least supplement, petrol.

Brazil, Zimbabwe and the USA produce ethanol as a renewable source of energy for cars. Since 2013, 94% of new cars in Brazil use a mixture of petrol and ethanol. As well as being a renewable resource, ethanol produces less pollution than petrol.

However, biofuels are not yet economical to produce. For example, the energy used to grow, fertilise, harvest and transport sugar cane, plus the cost of extracting the sugar and converting it to ethanol, uses more energy than the ethanol releases when burned.

There are also environmental costs, some of which are outlined in Chapter 19. Forests are being destroyed to plant soy beans or oil palms (Figure 18.1), removing the habitats of thousands of organisms, some of which, like the orang-utan, are on the verge of extinction.

▲ **Figure 18.1** A new palm oil plantation, replacing a rain forest

Another biofuel, oil from rapeseed or sunflower seed, can, with suitable treatment, replace diesel fuel. It is less polluting than diesel but more expensive to produce.

Bread

Yeast is the microorganism used in bread-making, but the only fermentation product needed is carbon dioxide. The carbon dioxide makes bubbles in the bread dough. These bubbles make the bread light in texture.

Flour, water, salt, oil and yeast are mixed to make a dough. Yeast has no enzymes for digesting the starch in flour, but adding water activates the amylases already present in flour. The amylases digest some of the starch to sugar. With highly refined white flour, adding sugar to the dough helps the process. The yeast then ferments the sugar to ethanol and carbon dioxide.

A protein called gluten gives the dough a sticky, elastic texture, which holds the bubbles of gas. The dough is repeatedly folded and stretched (kneaded) either by hand, in the home, or mechanically in the bakery. The dough is then left for an hour or two at a temperature of about 27 °C while the yeast uses sugar for respiration. The carbon dioxide bubbles build up, making the dough rise to about double its volume (Figure 18.2). The dough may then be kneaded again or put straight into baking tins and into an oven at about 200 °C. This temperature makes the bubbles expand more, kills the yeast and evaporates the small quantities of ethanol while the bread bakes.

▲ **Figure 18.2** Carbon dioxide produced by the yeast has caused the dough to rise

Fruit juice production

Pectinases are enzymes used to separate the juices from fruit like apples. The enzymes can be extracted from fungi (e.g. *Aspergillus niger*). They work by breaking down pectin, the jelly-like substance that sticks plant cell walls to each other. The enzymes can also be used to make fruit juice more transparent. During the breakdown process several different polysaccharides are released, which make the juice cloudy. Pectinases break these down to make the juice clearer. The sugars produced also make the juice sweeter.

Biological washing powders

Most commercial enzyme production involves protein-digesting enzymes (proteases) and lipid-digesting enzymes (lipases) for use in the food and textile industries. When combined in washing powders they remove stains in clothes caused by proteins (e.g. blood or egg) and lipids (e.g. grease and oil). Protein and lipid molecules tend to be large and insoluble. When they have been digested the products are small, soluble molecules, which can pass out of the cloth.

Biological washing powders save energy because they can be used to wash clothes at lower temperatures, so there is no need to boil water. However, if they are put in water at higher temperatures the enzymes become denatured (see Chapter 5) and so they are not as effective.

Fermenters

Lactose-free milk

Lactose is a type of disaccharide sugar found in milk and dairy products. Some people have problems with **lactose intolerance**. This is a digestive problem where the body does not produce enough of the enzyme lactase. As a result, the lactose stays in the gut, where it is fermented by bacteria. This causes symptoms like flatulence (wind), diarrhoea and stomach pains. Many foods contain dairy products, so people with lactose intolerance cannot eat them, or experience the symptoms described above. However, lactose-free milk is now produced using the enzyme lactase.

The lactase can be produced on a large scale by fermenting genetically-modified yeasts (e.g. *Kluyveromyces fragilis*) or fungi (e.g. *Aspergillus niger*) that carry the lactase gene.

A simple way to make lactose-free milk is to add lactase to milk. The enzyme breaks down lactose sugar into two monosaccharide sugars: glucose and galactose. Both can be absorbed by the intestine.

An alternative, large-scale method is to immobilise lactase on the surface of beads. The milk is then passed over the beads and the lactose sugar is effectively removed. This method avoids having the enzyme molecules in the milk because they stay on the beads.

Going further

The role of bacteria in yoghurt production

The food industry uses lactase in the production of milk products like yoghurt: it speeds up the process and makes the yoghurt taste sweeter.

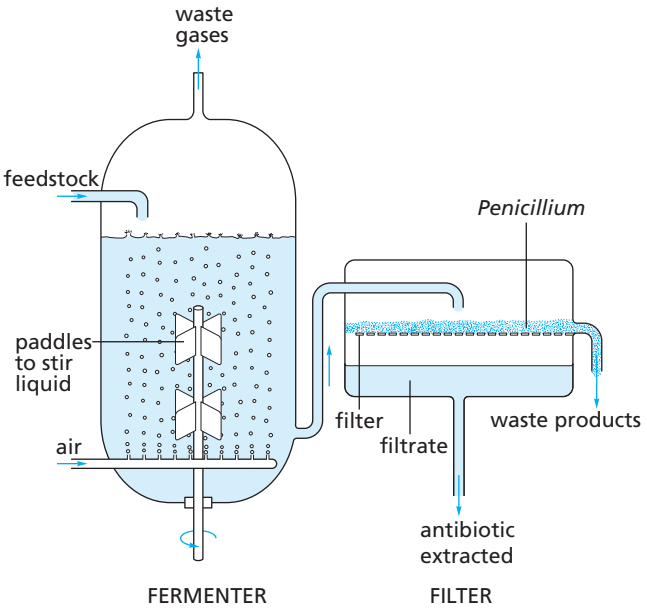
The two main species of bacteria used as starter cultures in the production of yoghurt are *Lactobacillus bulgaricus* and *Streptococcus thermophilus*. The bacterial culture is added to pasteurised milk at 42 °C. The function of the bacteria is to ferment lactose, the sugar present in milk. One of the products of the reaction is lactic acid, which gradually increases the acidity of the fermented milk to a pH of 4.5. The acidity causes the milk to clot, forming a soft gel (yoghurt) and gives the product its characteristic natural sharp flavour. Yoghurt is produced commercially in large fermenters (Figure 18.3).

▲ **Figure 18.3** Large-scale production of yoghurt in fermenters

Antibiotics

When microorganisms are grown in **fermenters** to produce antibiotics, it is not their fermentation products that are wanted but complex organic compounds, called antibiotics, that they synthesise (Figures 18.4 and 18.5).

Perhaps the best known antibiotic is penicillin, which is produced by the mould fungus *Penicillium* and was discovered by Sir Alexander Fleming in 1928 (see Chapter 12).



▲ **Figure 18.4** Principles of antibiotic production using a fermenter

▲ **Figure 18.5** A laboratory fermenter for antibiotic production, which will eventually be scaled up to 10000-litre fermentation vessels

Going further

Antibiotics

One of the richest sources of antibiotics is *Actinomycetes*. These are filamentous bacteria that look like microscopic mould fungi. The actinomycete *Streptomyces* produces the antibiotic streptomycin.

Penicillin is still an important antibiotic, but it is produced by mutant forms of a different species of *Penicillium* from the fungus studied by Fleming. The different mutant forms of the fungus produce different types of penicillin.

The penicillin types are chemically altered in the laboratory to make them more effective and to make them suitable for use with different diseases. Ampicillin, methicillin and oxacillin are examples.

Antibiotics attack bacteria in a variety of ways. Some of them upset the production of the cell wall. This stops the bacteria from reproducing or even causes them to burst open. Some affect protein synthesis, stopping bacterial growth.

Animal cells do not have cell walls, and the cell structures involved in protein production are different. As a result, antibiotics do not damage human cells, although they may produce some side-effects like allergic reactions.

Commercial production of insulin

Insulin can be produced in large quantities using fermenters. The DNA in bacteria is genetically modified to carry the human insulin gene (insulin is a protein). Bacteria respire aerobically, so air is pumped into the fermenter. Other conditions such as nutrient levels, temperature, pH and moisture are maintained at optimum levels so that the bacteria grow and reproduce rapidly. The nutrients are then reduced, and the bacteria begin to produce the insulin.

Penicillin

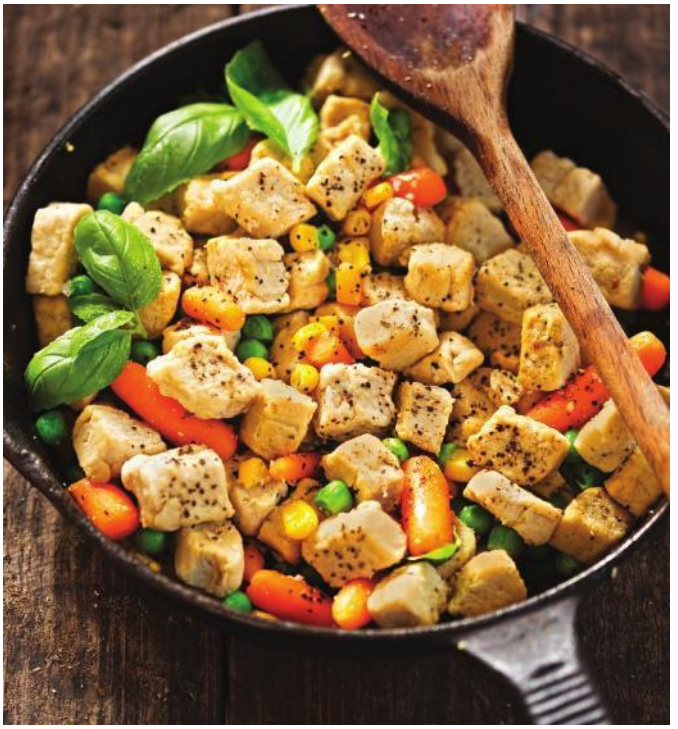
Antibiotics are produced in giant fermenting tanks, up to 100 000 litres in capacity. The tanks are filled with a nutrient solution. For penicillin production, the carbohydrate source is sugar, mainly lactose or corn-steep liquor, which is a by-product of the manufacture of cornflour and maize starch. It contains amino acids as well as sugars. Mineral salts are added and the pH is adjusted to between 5 and 6. The temperature is maintained at about 26 °C, air is blown through the liquid and it is stirred. The main features of industrial fermentation are shown in Figure 18.3.

A culture of the appropriate microorganism is added to the nutrient liquid and is allowed to grow for 24 to 48 hours. Sterile conditions are essential. If other bacteria or fungi get into the system, they can completely upset the process. As the nutrient supply reduces, the microorganisms begin to secrete their antibiotics into the medium.

The nutrient fluid containing the antibiotic is filtered off and the antibiotic extracted by crystallisation or other methods.

Mycoprotein

Mycoprotein is a protein-rich meat substitute extracted from fungi. The filamentous fungus, *Fusarium venenatum*, is found in soil. Mycoprotein is becoming more popular because it contains no cholesterol and is lower in saturated fats than protein in meat products. It is suitable as part of a vegan diet (which contains no animal products), partly because of its high protein content. Its manufacture has been developed so it can be made commercially. It is fermented in a similar way to antibiotics and enzymes, using glucose and salts as the feedstock. One mycoprotein product is called *Quorn* (Figure 18.6, also see Chapter 8 – Going further box, 'Vegetarian and vegan diets', and Tables 8.2 and 8.3).



▲ **Figure 18.6** Food made with pieces of Quorn

Conditions that need to be controlled in a fermenter

These have been described in the section on the commercial production of penicillin, above.

Table 18.1 summarises these.

▼ **Table 18.1** Conditions that need to be controlled in a fermenter in the manufacture of an antibiotic

condition	details
temperature	maintained at around 26 °C. Heat is generated during fermentation, so the mixture needs to be cooled
pH	slightly acidic – 5 to 6
oxygen	sterilised air is blown into the mixture through air pipes and the mixture is stirred to aerate it
nutrient supply	depends on what is being manufactured, but for penicillin the feedstock is molasses or corn-steep liquor
waste products	depends on what is being manufactured, but for penicillin they are the waste nutrient fluid with bacterial residue. These are quite hazardous because of the presence of traces of antibiotic. Gases given off may include carbon dioxide.

Test yourself

1 Outline the biology involved in making bread.
2 State how DNA in a bacterium is different from DNA in an animal cell.
3 Give two reasons why bacteria are more suitable for use in genetic modification than, for example, mammals.
4 Some people are lactose in tolerant. Explain how biotechnology can be used to allow people with this condition to eat milk products.

Genetic modification

FOCUS POINTS

- ★ What is genetic modification and when is it used?
- ★ How is genetic modification achieved?
- ★ What are the advantages and disadvantages of genetically modifying crops?

Key definitions

Genetic modification is changing the genetic material of an organism by removing, changing or inserting individual genes.

As stated in the definition, genetic modification involves changing the genetic material of an organism by removing, changing or inserting material. It is achieved by transferring one or more genes from one organism to another organism, which is usually a totally unrelated species. The process often uses bacteria because of their ability to make complex molecules (e.g. proteins) and their rapid reproduction rate.

Use of bacteria in genetic modification

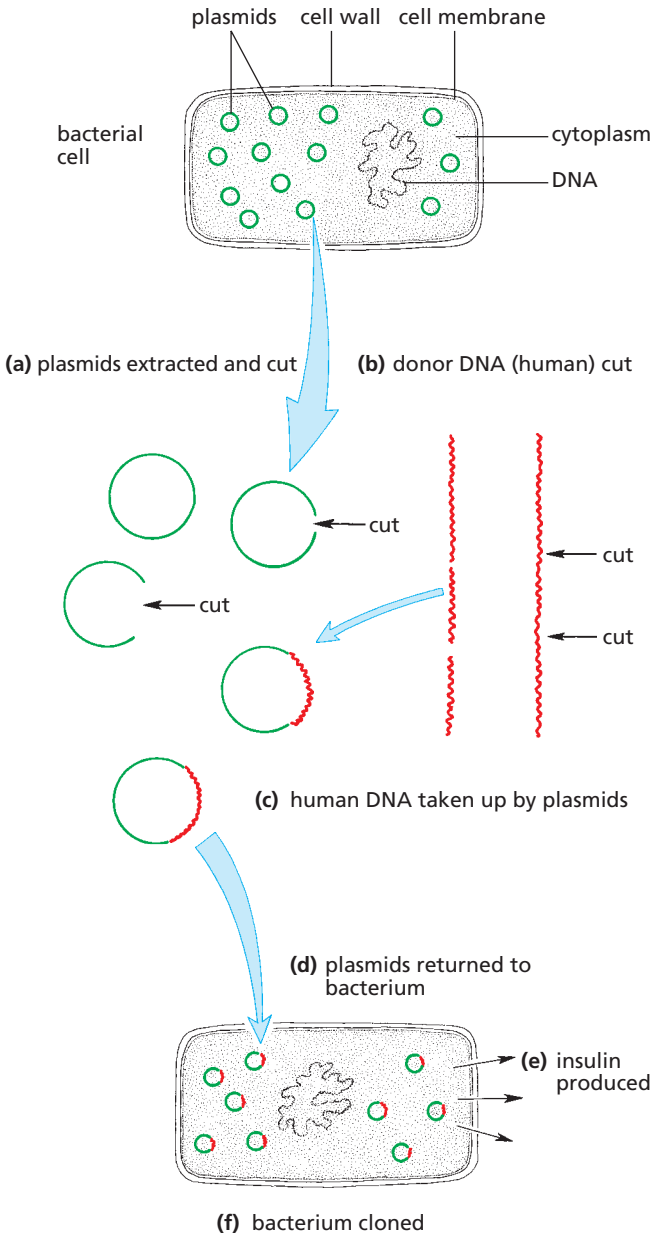
To understand the principles of genetic modification you need to know something about bacteria (Figure 1.9). Bacteria are microscopic single-celled organisms with cytoplasm, cell membranes and cell walls, but without a proper nucleus. Genetic control in a bacterium is carried out by a piece of circular DNA. There are also a number of small, circular pieces of DNA called plasmids present in the cytoplasm. Scientists have found a way of cutting sections out of DNA. For example, the gene for insulin can be cut from a human DNA molecule. Plasmids are removed from bacteria and cut open. When the human DNA is added to a suspension of the plasmids, some of the human DNA attaches to some of the plasmids. They are treated so that they close up again. The bacteria can be stimulated to take up the plasmids. Figure 18.7 summarises the process of genetic modification. Given suitable nutrient solutions, these bacteria containing the plasmids reproduce rapidly by mitosis (Chapter 17) to make millions of cells. Each daughter bacterium will contain the same DNA and the same plasmids as the parent. The human DNA in the plasmids continues to produce the same protein as it did in the human cells. In the example mentioned, this would be the protein, insulin (Chapter 14).

The bacteria are cultured in special vessels called fermenters (Figure 18.4) and the insulin that they produce can be extracted from the culture medium and purified for use in treating diabetes (Chapter 14).

Variations in genetic modification

The plasmids are said to be the *vectors* that carry the human DNA into the bacteria and the technique is sometimes called *gene-splicing*. Using plasmids is only one type of genetic modification. The vector may be a virus rather than a plasmid; the DNA may be inserted directly, without a vector; the donor DNA may be synthesised from nucleotides rather than extracted from cells; yeast may be used instead of bacteria. The outcome, however, is the same. DNA from one species is inserted into a different species and made to produce its normal proteins.

In the example shown in Figure 18.7, the gene product, insulin, is harvested and used to treat diabetes. In other cases, genes are inserted into organisms to promote changes that may be beneficial. Bacteria or viruses are used as vectors to deliver the genes. For example, a bacterium is used to deliver a gene for herbicide resistance in crop plants.



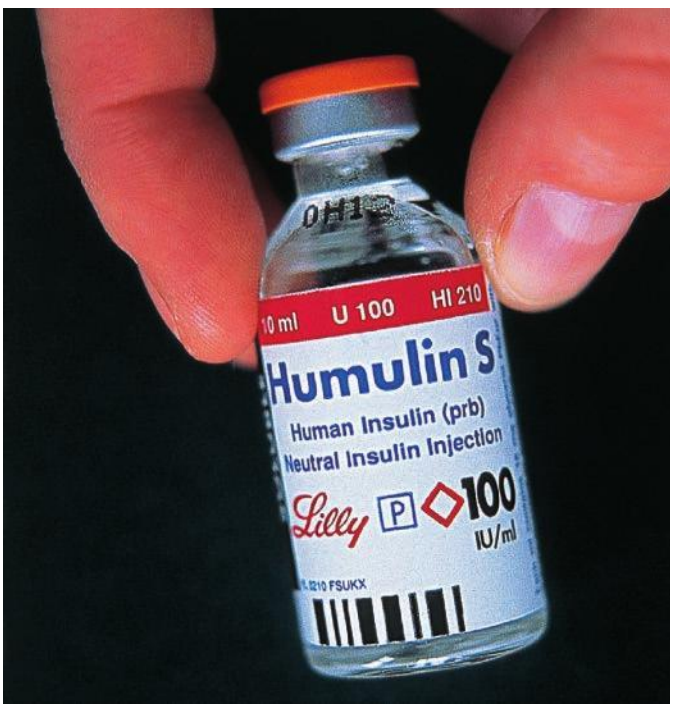
▲ **Figure 18.7** The principles of genetic modification

Applications of genetic modification

The following section gives only a few examples of genetic modification, a rapidly advancing process. Some products, like insulin, are in full-scale production. A few genetically modified (GM) crops (e.g. maize and soya bean) are being grown on a large scale in the USA. Many other projects are still at the experimental stage, undergoing trials, awaiting approval by regulatory bodies or simply on a wish list.

Production of human insulin

As stated in the previous section, human proteins like insulin can be produced by genetically modified bacteria, and it has been in use since 1982. The human insulin gene is inserted into bacteria, which then secrete human insulin. The human insulin produced in this way (Figure 18.7) is purer than insulin prepared from pigs or cattle, which sometimes triggers allergic reactions because of traces of foreign protein. The GM insulin is acceptable to people with a range of religious beliefs who may not be allowed to use insulin from cows or pigs.



▲ **Figure 18.8** Human insulin prepared from genetically modified bacteria. Though free from foreign proteins, it does not suit all patients

Going further

Hepatitis B vaccine

The gene for the protein coat of the hepatitis virus is inserted into yeast cells. When these are cultured they produce a protein that acts as an antigen (a vaccine, Chapter 12) and promotes the production of antibodies to the disease.

Transgenic plants have been modified to produce vaccines that can be taken effectively by mouth. These include vaccines against rabies and cholera. Several species of plant have been used, including the banana, which is cheap and widespread in the tropics, can be eaten without cooking and does not produce seeds (Figure 18.8).

▲ **Figure 18.9** It is important to ensure that plants modified to produce drugs and vaccines cannot find their way, by chance, into the human food chain. Strict control measures must be applied

GM crops

Genetic modification has huge potential benefits in agriculture but, apart from a relatively small range of crop plants, most developments are in the experimental or trial stages. In the USA, 94% of the soya bean crop and 92% of the maize harvest consist of genetically modified plants, which are resistant to **herbicides** and insect pests.

In many countries, GM crops are grown only on a trial basis and there is resistance to their growth and the presence of GM products in food.

Pest resistance

The bacterium, *Bacillus thuringiensis*, produces a toxin that kills caterpillars and other insect larvae. The toxin has been in use for some years as an insecticide. The gene for the toxin has been successfully introduced into some plant species such as maize, cotton and soybean using a bacterial vector. The plants produce the toxin and show increased resistance to attack by insect larvae. The gene is also passed on to the plant's offspring. Unfortunately, there are signs that insects are developing immunity to the toxin.

Most American GM maize carries a pesticide gene, which reduces the damage caused by the stem-boring larva of a moth (Figure 18.9).

▲ **Figure 18.10** The maize stem borer can cause considerable losses by killing young plants

Herbicide resistance

Some of the most effective herbicides are those, like glyphosate, which kill any green plant but become harmless as soon as they reach the soil. These herbicides cannot be used on crops because they kill the crop plants as well as the weeds. A gene for an enzyme that breaks down glyphosate is introduced into a plant cell culture (Chapter 16). Most American GM maize has a herbicide-resistant gene. This should lead to a reduced use of herbicides. Some scientists suspect that glyphosate is carcinogenic, and it is being banned from use in some countries.

Providing additional vitamins

Traditionally, vitamins and minerals have been added to food to boost their nutritional value or given in tablet form to help people avoid deficiency diseases. The development of GM technology is now allowing scientists to study other ways of helping populations to achieve a balanced diet.

Over 100 million children in the world are deficient in vitamin A. This deficiency often leads to blindness.

A gene for beta-carotene, a precursor of vitamin A, can be inserted into plants to alleviate this widespread deficiency. Golden rice (see Figure 18.10)

was a variety of rice developed through genetic modification for this purpose. In countries where rice is a staple food, the use of golden rice could reduce the incidence of the condition called night blindness – a serious problem which is estimated to kill 670 000 children under the age of 5 each year. This is not, of course, the only way to increase vitamin A availability, but it could make a significant contribution.

Advantages and disadvantages of genetic modification

Crops

Although GM crops show increased yields, one of the objections is that only the farmers and the chemical companies in the industrialised world have benefited. So far, genetic modification has done little to improve yields or quality of crops in the newly industrialising world, except perhaps in China. However, there are many trials in progress, which have hopes of doing just that. Here are just a few examples.

Inadequate intake of iron is one of the major dietary deficiencies (Chapter 8) worldwide. An enzyme in some plant roots enables them to extract more iron from the soil. The gene for this enzyme can be transferred to plants, like rice, enabling them to take in iron from iron-deficient soils.

Some acid soils contain levels of aluminium that reduce yields of maize by up to 8%. About 40% of soils in tropical and subtropical regions have this problem. A gene introduced into maize produces citrate, which binds the aluminium in the soil and releases phosphate ions. After 15 years of trials, the GM maize was made available to farmers, but pressure from environmental groups has blocked its adoption. The USA, Brazil and Argentina are the only countries that grow GM maize at present.

As a result of irrigation, much agricultural land has become salty and unproductive. Transferring a gene for salt tolerance from, for example, mangrove plants to crop plants could bring these regions back into production.

If the gene, or genes, for **nitrogen fixation** (Chapter 19) from bacteria or leguminous plants could be introduced to cereal crops, yields could be increased without the need to add fertilisers.

Similarly, genes for drought resistance would make dry areas available for growing crops.

Genes coding for human vaccines have been introduced into plants.

In conventional cross-breeding, the genes transferred come from the same, or a closely related, species. However, in cross-breeding the whole range of genes is transferred and this has sometimes had bad results when genes other than the target genes have combined to produce harmful products. Genetic modification offers the advantage of transferring only those genes that are required.

The differences between the genetic make-up of different organisms is not as great as we tend to think. Plants and animals share 60% of their genes and humans have 50% of their genes in common with fruit flies. Not all genetic modification involves transfer of alien genes. In some cases, it is the plant's own genes that are modified to improve its success in the field.

One of the possible harmful effects of planting GM crops is that their modified genes might get into wild plants. If a gene for herbicide resistance found its way, via pollination, into a weed plant, this plant might become resistant to herbicides and so become a super weed. The purpose of field trials is to assess the likelihood of this happening. Until it is certain that this is a tiny risk, licences to grow GM crops will not be issued.

To prevent the transfer of pollen from GM plants, other genes can be introduced. These genes would stop the plant from producing pollen and stimulate the seeds and fruits to develop without fertilisation. This is a process that occurs naturally in many cultivated and wild plants.

GM food

This is food prepared from GM crops. Most genetic modifications are aimed at increasing yields rather than changing the quality of food. However, it is possible to improve the protein, mineral or vitamin content of food (Figure 18.10) and the shelf life of some products.

One of the worries is that the bacteria for delivering recombinant DNA contain genes for antibiotic resistance. The antibiotic-resistant properties are used to select only those bacteria that have taken up the new DNA. If, in the intestine, the DNA managed to get into potentially harmful bacteria, it might make them resistant to antibiotic drugs.

Although there is no evidence to suggest this happens in experimental animals, the main biotech companies are trying to find methods of selecting bacterial vectors without using antibiotics.

Another concern is that GM food could contain pesticide residues or substances that cause allergies (allergens). However, all GM products are rigorously tested for toxins and allergens over many years, far more so than any products from conventional cross-breeding. The GM products must be passed by a series of regulatory and advisory bodies before they are released onto the market. In fact, only a handful of GM foods are available. One of these is soya, which is included, in one form or another, in 60% of processed foods.

Golden rice (Figure 18.11) carries a gene that is responsible for making beta-carotene, a precursor of vitamin A.

▲ **Figure 18.11** Samples of golden rice and non-GM rice

However, some argue that there is a danger of the precursor changing into other, toxic chemicals once eaten. So far, only the Philippines and Bangladesh allow the GM golden rice to be grown.

There were also concerns about a reduction in **biodiversity** as a result of the introduction of GM species. Subsistence farmers could also be tied to large agricultural suppliers who may then manipulate seed prices.

Apart from specific hazards, there is also a sense of unease about introducing genes from one species into a totally different species. This is something that does not happen in nature and so the long-term effects are not known.

At least some of the protests against GM crops may be ill-judged (Figure 18.12).

▲ **Figure 18.12** Ill-judged protest. These vandalised poplars carried a gene that softened the cell walls, reducing the need for environmentally damaging chemicals used in paper making. They were also all female plants so no pollen could have been produced

Bacteria

Bacteria are particularly useful in genetic modification because they have a rapid reproduction rate and there is a lack of ethical concerns over their manipulation and growth. Also, the genetic code in bacteria is shared with all other organisms.

However, there is also some concern about the use of genetically modified bacteria, such as to produce human insulin, because there is the risk that the bacteria could pass the human genes they carry to other bacteria, with unknown consequences.

Test yourself

5 Outline how genetic modification is carried out for each of the following:
   - **a** to produce human proteins
   - **b** to make crop plants resistant to insect pests
   - **c** to improve the nutritional qualities of crop plants.

6 Make a table to outline the advantages and disadvantages of GM crops.

7 Describe how genetic modification can be used to solve major worldwide dietary deficiencies like vitamin deficiencies.

Practical work

Safety

- Eye protection must be worn.
- Wipe up any spillages immediately and rinse the cloth thoroughly with water. Do not allow spillages to dry up.

1 Investigating the use of pectinase in fruit juice production

- Make 100 cm^3 of apple purée using a liquidiser, or use a tin of apple purée.
- Transfer the purée to a 250 cm^3 beaker.
- Using a syringe or small measuring cylinder, add 5 cm^3 of 50% pectinase, stir the mixture and leave it for about 5 minutes.
- Place a funnel in the top of a 100 cm^3 measuring cylinder and line the funnel with a folded filter paper.
- Transfer the purée into the filter funnel and leave it in a warm place for up to 24 hours.
- Set up other measuring cylinders in the same way, with purée left to stand at different temperatures to compare the success of juice extraction.

Result

Juice is extracted from the purée. It collects in the measuring cylinder and is transparent (it has been clarified).

Interpretation

Pectinase breaks down the apple tissue, releasing sugars in solution. More juice collects in the measuring cylinder when the purée has been kept in warm conditions; colder temperatures slow down the process.

Further investigation

If other enzymes are available, try comparing cellulase and amylase with pectinase. Combinations of these could be used to find out which is the most effective in extracting the juice. Remember to control variables to make a fair comparison.

2 Investigating the use of biological washing powder

- Break an egg into a plastic beaker and whisk it with a fork, spatula or stirring rod until thoroughly mixed.
- Cut up four pieces of white cloth to make squares 10 cm × 10 cm, smear egg evenly onto each of them and leave to dry.
- Set up four 250 cm^3 beakers as follows:
  - **A** 100 cm^3 warm water with no washing powder.
  - **B** 5 cm^3 (1 level teaspoon) of non-biological washing powder dissolved in 100 cm^3 warm water.
  - **C** 5 cm^3 (1 level teaspoon) of biological washing powder dissolved in 100 cm^3 warm water.
  - **D** 5 cm^3 (1 level teaspoon) of biological washing powder dissolved in 100 cm^3 water and boiled for 5 minutes, then left to cool until warm.
- Place a piece of egg-stained cloth in each beaker and leave for 30 minutes.
- Remove the pieces of cloth and compare the effectiveness of each washing process.

Results

The piece of cloth in beaker **C** is most effectively cleaned, followed by **B** and then **D**. The cloth in **A** is largely unchanged.

Interpretation

The enzymes in the biological washing powder break down the proteins and fats in the egg stain to amino acids and fatty acids and glycerol. These are smaller, soluble molecules, which can escape from the cloth and dissolve in the water. Non-biological washing powder is less effective because it does not contain enzymes. Boiled biological washing powder is not very effective because the enzymes in it have been denatured. Beaker A was a control, with no active detergent or enzymes. Soaking the cloth in warm water alone does not remove the stain.

3 Action of lactase

This investigation uses glucose test strips (Diastix). They are used by people with diabetes to test for glucose in their urine (see 'Homeostasis' in Chapter 14 for details of diabetes). The strips do not react to the presence of other sugars (lactose, sucrose, etc.)

- Pour 25 cm^3 warm, fresh milk into a 100 cm^3 beaker.
- Test the milk for glucose with a glucose test strip.
- Measure out 2 cm^3 of 2% lactase using a syringe or pipette and add this to the milk.
- Stir the mixture and leave for a few minutes.

Result

Milk gives a negative result for glucose, but milk exposed to lactase gives a positive result.

Interpretation

Lactase breaks down the lactose in milk, as shown in the equation below.

$$\text{lactose} \xrightarrow{\text{lactase}} \text{glucose} + \text{galactose}$$

Note: Milk sometimes contains traces of glucose. If the milk gives a positive result with the glucose test strip, an alternative method would be to use a solution of lactose instead of milk. However, the amount of glucose in the milk, as indicated by the colour change on the test strip, should increase after treatment with lactase.

Practical work questions

1. In the modification of the experiment to study the effect of temperature on fruit juice production, suggest two factors that should be controlled to make sure the results are reliable.
2. In experiment 2, investigating the use of biological washing powder, the results are based on a ***qualitative*** analysis (you were looking at the appearances of the stains after washing). Describe how you could modify the method to carry out the same investigation but collect ***quantitative*** results (results you can measure).
3. In experiment 3, Diastix testing strips were used to test for the presence of glucose.
   a. If those test strips were not available, describe how you could test for glucose.
   b. A statement in the method suggested that milk sometimes contains traces of glucose. Describe how your test could distinguish between a sample with a trace of glucose and a sample with a lot of glucose present.

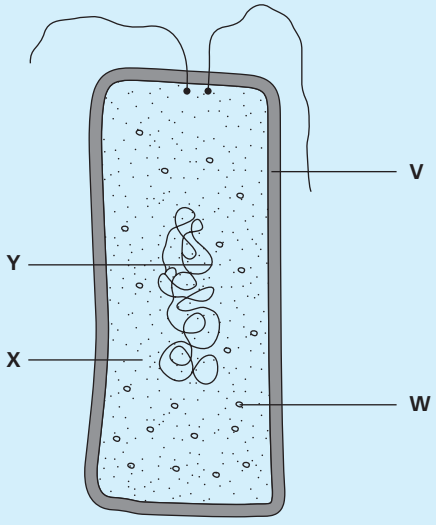
Revision checklist

After studying Chapter 18 you should know and understand the following:

- ✔ Bacteria are useful in biotechnology and genetic modification because of their ability to make complex molecules and their rapid reproduction.
- ✔ Bacteria are useful in biotechnology and genetic modification because of lack of ethical concerns over their manipulation and growth.
- ✔ The genetic code in bacteria is shared with all other organisms.
- ✔ Bacteria contain DNA in the form of plasmids, which can be cut open to insert genes.
- ✔ Biotechnology is the application of living organisms, systems or processes in industry, often using microorganisms in processes called fermentations.
- ✔ The required product of biotechnology may be the organism itself (e.g. mycoprotein) or one of its products (e.g. ethanol).
- ✔ Yeasts can be used to make biofuel and for bread-making.
- ✔ Pectinase can be used to extract fruit juices.
- ✔ Lipase and protease enzymes are used in biological washing powders to remove fat and protein stains.
- ✔ Lactase is used to produce lactose-free milk.
- ✔ Fermenters are used in the production of antibiotics like penicillin on an industrial scale.
- ✔ Genetic modification is changing the genetic material of an organism by removing, changing or inserting individual genes.
- ✔ Examples of genetic modification include
  - the insertion of human genes into bacteria to produce human proteins (e.g. insulin)
  - the insertion of genes into crop plants to confer resistance to herbicides or insect pests
  - the insertion of genes into crop plants to improve nutritional qualities.
- ✔ There are advantages of genetically modifying crops, such as giving them resistance to pests and herbicides and increasing their nutritional qualities.
- ✔ There is concern that the genes introduced into crop plants might spread to wild plants.
- ✔ There is concern about the use of genetically modified bacteria, such as to produce human insulin, because there is the risk that the bacteria could pass the human genes they carry to other bacteria, with unknown consequences.

Exam-style questions

1 The diagram shows a bacterial cell.



a Identify the labelled parts. [4]

b Explain why bacterial cells are very useful organisms in the process of genetic modification. [2]

2 **a** Name the waste product made by yeast which is used

i) as a biofuel [1]

ii) in baking. [2]

b Explain why biological washing powders can be more effective in removing stains than non-biological washing powders. [4]

3 Copy and complete the table, using ticks (✓) and crosses (✗), to compare the structure of a bacterial cell with that of an animal cell. [5]

	Present in	
cell part	**bacterial cell**	**animal cell**
cell wall		
membrane		
nucleus		
plasmid		
cytoplasm		

4 A fermenter is used in the large-scale production of human insulin.
Suggest why

a the air being blown into the fermenter is sterilised [1]

b the waste products of the fermentation of antibiotics are considered to be hazardous [2]

c the temperature of the liquid may rise. [3]

5 **a** Define the term *genetic modification*. [2]

b Outline how biotechnology can be used to produce milk which is safe to drink by people who are lactose intolerant. [5]

6 Outline **two** advantages and **two** disadvantages of genetically modified crops. [4]

19 Relationships of organisms with one another and with the environment

Focus

At the beginning of this book you were introduced to a wide range of organisms, mainly plants and animals. Now we can look at the relationships between them.

Photosynthesising plants can make their own food from simple molecules, while animals have to find their nutrition ready-made. But not all animals eat plants, so how does the energy get passed to them? What happens to all the nutrients built up inside organisms when they die? This chapter will help you find the answers.

Energy flow

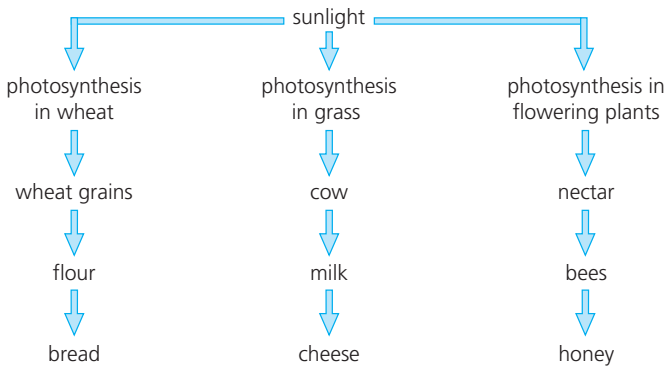
FOCUS POINTS

- ★ Where does the energy come from in biological systems?
- ★ How does it flow through living organisms before it flows back to the environment?

Nearly all living things depend on the Sun to provide energy. This is harnessed by photosynthesising plants and the energy is then passed through food chains.

Dependence on sunlight

With the exception of atomic energy and tidal power, all the energy released on Earth comes from sunlight. The energy released by animals comes from plants that they or their prey eat. The plants depend on sunlight for making their food. Photosynthesis is a process in which light energy is trapped by plants and converted into chemical energy (stored in molecules like carbohydrates, lipids and proteins). Since all animals depend, in the end, on plants for their food, they depend indirectly on sunlight. A few examples of our own dependence on photosynthesis are given below.



Nearly all the energy released on the Earth can be traced back to sunlight. Coal comes from tree-like plants buried millions of years ago. These plants absorbed sunlight for their photosynthesis when they were alive. Petroleum was also formed millions of years ago from the partly decayed bodies of microscopic algae that lived in the sea. These had all absorbed sunlight for photosynthesis.

Today it is possible to use mirrors and solar panels to collect energy from the Sun directly. However, the best way of trapping and storing energy from sunlight is to grow plants and make use of their products. These include starch, sugar, oil and wood, for food or as energy such as ethanol in motor fuel (see page 313).

Eventually, through one process or another, all the chemical energy in organisms is passed to the environment. However, it is not a cyclical process like those described later in this chapter.

Food chains and food webs

FOCUS POINTS

- ★ What terms are used to describe organisms in feeding relationships?
- ★ How do organisms obtain their energy?
- ★ How can we display the feeding relationships between living organisms?
- ★ What is a pyramid of energy and why is it a good way of representing a food chain?
- ★ Why is energy transfer between living organisms inefficient?
- ★ How can we become more energy efficient in the food we eat?

Key definitions

A **food chain** shows the transfer of energy from one organism to the next, beginning with a producer.

A **food web** is a network of interconnected food chains.

A **producer** is an organism that makes its own organic nutrients, usually using energy from sunlight, through photosynthesis.

A **consumer** is an organism that gets its energy by feeding on other organisms.

A **herbivore** is an animal that gets its energy by eating plants.

A **carnivore** is an animal that gets its energy by eating other animals.

A **decomposer** is an organism that gets its energy from dead or waste organic material.

A **trophic level** is the position of an organism in a food chain, food web, **pyramid of numbers** or **ecological pyramid**.

Interdependence means the way in which living organisms depend on each other in order to remain alive, grow and reproduce. For example, bees depend on pollen and nectar from flowers for their food. Flowers depend on bees for pollination (Chapter 16). So, bees and flowers are interdependent.

Food chains

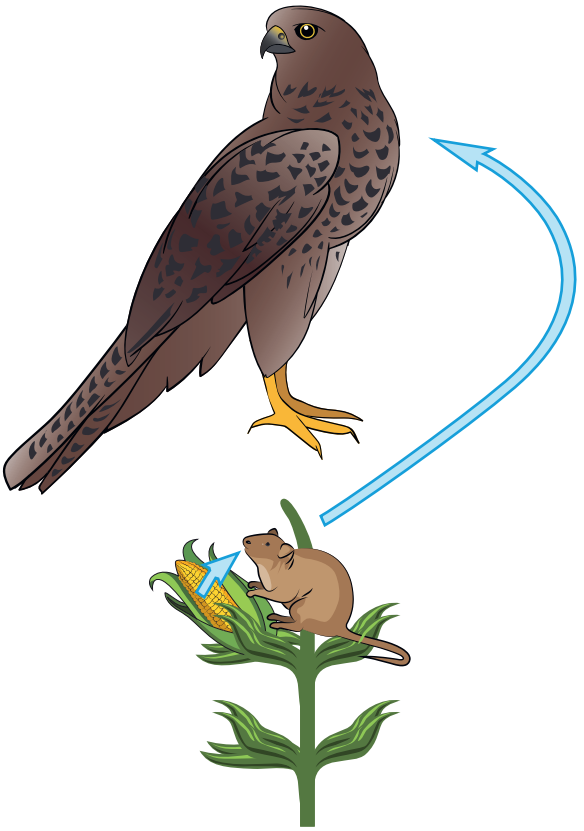
FOCUS POINTS

- ★ What are pyramids of numbers and pyramids of biomass?
- ★ What is a trophic level?

One important way in which organisms depend on each other is for their food. Many animals, like rabbits, feed on plants. Plant-eating animals are called herbivores. Animals that eat other animals are called carnivores.

All animals depend on plants for their food. Wolves may eat hares, but hares feed on grass. A hawk eats a lizard, the lizard has just eaten a grasshopper, but the grasshopper was feeding on a grass blade. This relationship is called a food chain (Figure 19.1).

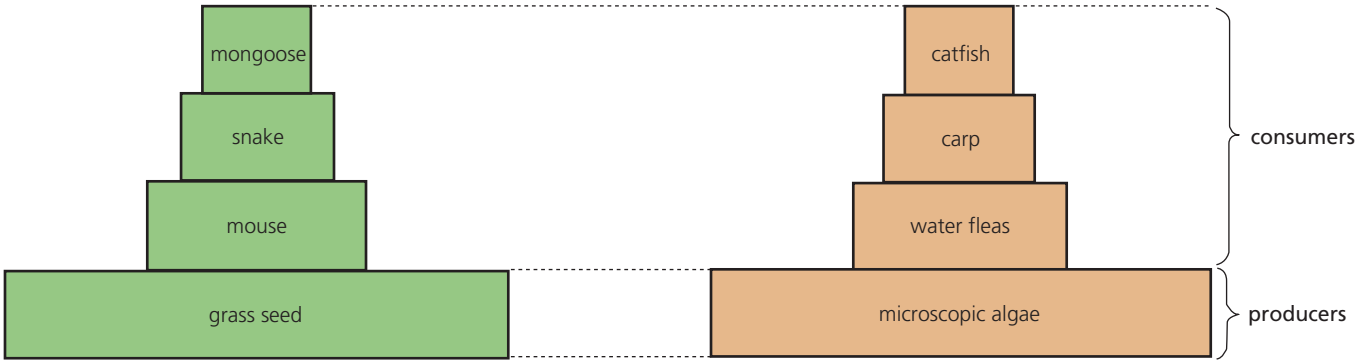
There are usually large numbers of organisms at the beginning of a food chain while the animals at the end of the chain are often larger and fewer in number. The food pyramids in Figure 19.2 show this relationship. There will be millions of microscopic, single-celled algae in a lake (Figure 19.3(a)). These will be eaten by the larger but less numerous water fleas and other crustacea (Figure 19.3(b)), which in turn will become the food of fish like small carp. The hundreds of carp may be able to provide enough food for only four or five large carnivores, like catfish.



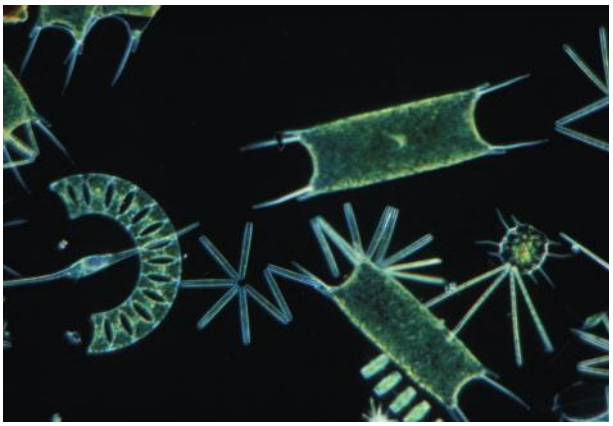
▲ **Figure 19.1** A food chain. The mouse eats the maize grains; the kestrel eats the mouse

The position of an organism in a food chain is called its trophic level (its feeding level). The organisms at the base of the food pyramids in Figure 19.2 are plants. Plants produce food from carbon dioxide, water and mineral ions (see 'Photosynthesis', Chapter 6), so they are called producers. The animals that eat the plants (herbivores) are called primary consumers (e.g. mice). Animals that prey on the plant-eaters (carnivores) are called secondary consumers (e.g. snakes) and these may be eaten by tertiary consumers (e.g. a mongoose or hawk) (Figure 19.4).

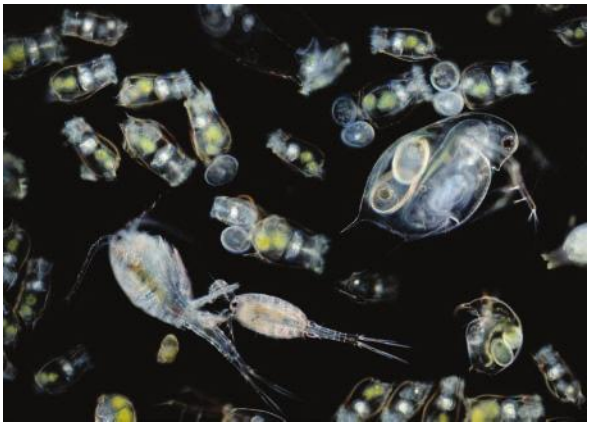
The microscopic organisms that live in the surface waters of the sea or fresh water are called, collectively, plankton. The single-celled algae (see Chapter 2) are the phytoplankton. They are surrounded by water, mineral ions and dissolved carbon dioxide. Their chloroplasts absorb sunlight and use its energy for making food by photosynthesis. Phytoplankton is eaten by small animals in the zooplankton, mainly crustacea (see Chapter 2). Fish like small carp will eat the crustacea.



▲ **Figure 19.2** Examples of food pyramids (pyramids of numbers)



(a) phytoplankton (×100). These microscopic algae form the basis of a food pyramid in the water.



(b) zooplankton (×20). These crustacea will eat microscopic algae.

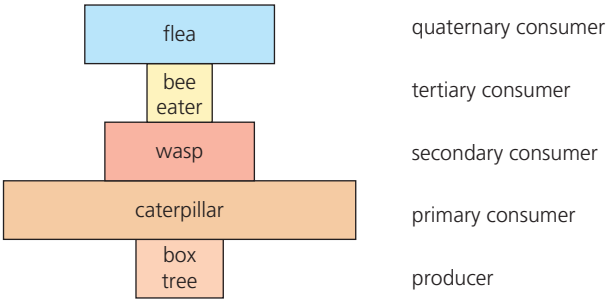
▲ **Figure 19.3** Plankton

▲ **Figure 19.4** The mongoose, a secondary or tertiary consumer

Pyramids of numbers

The width of the bands in Figure 19.2 is meant to represent the relative number of organisms at each trophic level. So, the diagrams are sometimes called pyramids of numbers.

However, sometimes a pyramid of numbers would not show the same effect. For example, a single lime tree may provide food for thousands of aphids (greenfly). One box tree may feed hundreds of caterpillars. In these cases, the pyramid of numbers is upside-down, as shown in Figure 19.5.

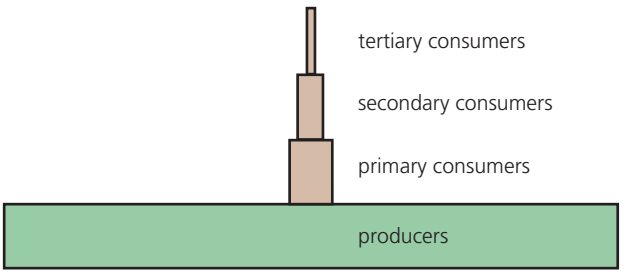


▲ **Figure 19.5** An inverted pyramid of numbers

Pyramids of biomass

Displaying food chains using pyramids of numbers, like those shown in Figure 19.5, can produce inverted pyramids. This is because the top consumers may be represented by large numbers of very small organisms, for example, fleas feeding on a bird like a bee-eater. The way around this problem is to consider not the single tree, but the mass of the leaves that it produces in the growing season, and the mass of the insects that can live on them. **Biomass** is the term used when the mass of living organisms is being considered, and pyramids of biomass can be constructed as in Figure 19.6. A **pyramid of biomass** is nearly always the correct pyramid shape.

In Figure 19.6 the width of the horizontal bands is proportional to the masses (dry weight) of the organisms in a shallow pond.



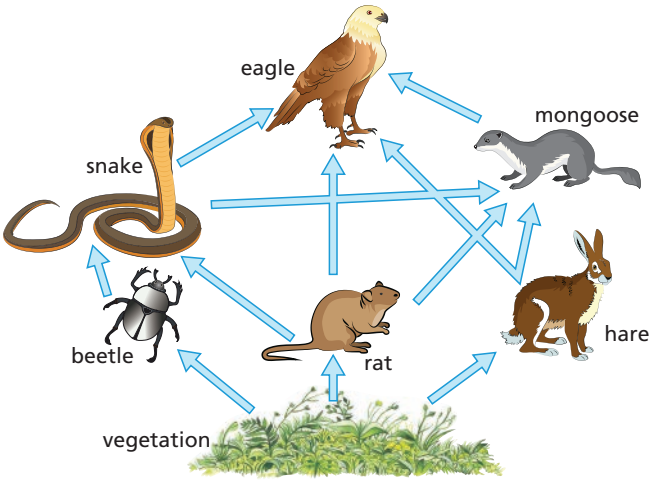
▲ **Figure 19.6** Biomass (dry weight) of living organisms in a shallow pond (grams per square metre)

An alternative is to calculate the energy available in a year's supply of leaves and compare this with the energy needed to maintain the population of insects that feed on the leaves. This would produce a **pyramid of energy**, with the producers at the bottom having the greatest amount of energy. Each successive trophic level would show a reduced amount of energy.

The elements that make up living organisms are recycled, i.e. they are used over and over again (see next section). This is not the case with energy, which flows from producers to consumers and is eventually lost to the atmosphere as heat.

Food webs

Food chains are not as straightforward as described above. Most animals eat more than one type of food. A mongoose, for example, does not feed entirely on snakes but takes lizards, fish and birds' eggs in its diet too. To show these relationships more accurately, a food web can be drawn up (Figure 19.7).



▲ **Figure 19.7** A food web

The food webs for land, sea and fresh water, or for ponds, rivers and streams, will all be different. Food webs will also change with the seasons when the food supply changes.

If some event disturbs a food web, all the organisms in it are affected in some way. For example, if the rats in Figure 19.7 were to die out, the mongooses, snakes and eagles would eat more beetles and hares. Something like this has happened in India. Cattle were being treated illegally with a drug to ease pain. If they died, white-rumped vultures would feed on the flesh. The white-rumped vultures suffered kidney failure and many died from the drug, which was still in the cattle meat. The vulture population has declined by 99.9%. However, the populations of feral dogs have grown rapidly, because they now have less competition and are not so badly affected by the poison.

Energy transfer

Study Figure 19.1. When herbivorous animals eat a plant (the mice feeding on maize grains), the chemical energy stored in that maize grain is transferred to

the herbivores. When a carnivore (kestrel) eats the herbivore, the carnivore gains the energy stored in the herbivore. If the carnivore is eaten by another carnivore the energy is transferred again.

Use of sunlight

To try and estimate just how much life the Earth can support, it is necessary to examine how efficiently the Sun's energy is used. When the Sun's energy falls onto grassland, about:

Worked example

We are going to create a food web based on the following organisms:

caterpillar duck grass hawk lime tree lizard

maize mouse robin snail snake worm

When you are going to construct a food web, work from the bottom of your paper.

Step 1 Select all the producers (green plants) from the set of organisms you have been given. List them all along the bottom of the page. The order is not important.
Label these as producers.

grass lime tree maize **producers**

Step 2 Select all the primary consumers from the set of organisms.

Make a row of these across your page, leaving a space between them and the producers so you can add arrows later. Label the row as primary consumers.

worm caterpillar mouse snail **primary consumers**

grass lime tree maize **producers**

Step 3 Select all the secondary consumers (carnivores) from the set of organisms. You will have to decide if any of these are tertiary consumers and keep them back for the final row.

Make a row of the secondary consumers across your page, leaving a space between them and the primary consumers. Label the row as secondary consumers.

robin duck lizard snake **secondary consumers**

worm caterpillar mouse snail **primary consumers**

grass lime tree maize **producers**

Step 4 Select all the tertiary consumers (also carnivores) from the set of organisms.

Make a row of these across your page, leaving a space between them and the secondary consumers. Label the row as tertiary consumers.

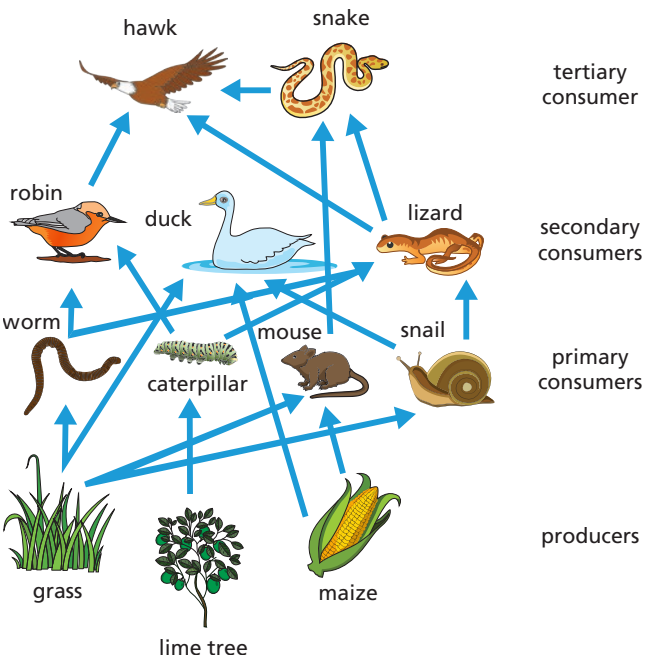
hawk **tertiary consumer**

robin duck lizard snake **secondary consumers**

worm caterpillar mouse snail **primary consumers**

grass lime tree maize **producers**

Step 5 Finally, you need to link the animals and plants with arrows. Remember that the arrow always points from the food to the eater of that food (it shows the flow of energy through the food web).



Note: Some of the organisms may be difficult to place, for example, the snake, because it acts as secondary and tertiary consumer, or the hawk because it is both a tertiary and quaternary consumer.

Tasks

1 Draw a food chain based on the lime tree. Label the trophic levels.

2 a A student wanted to draw a pyramid of numbers for the food chain involving the grass, worm, robin and hawk. What extra information would she need to do this?

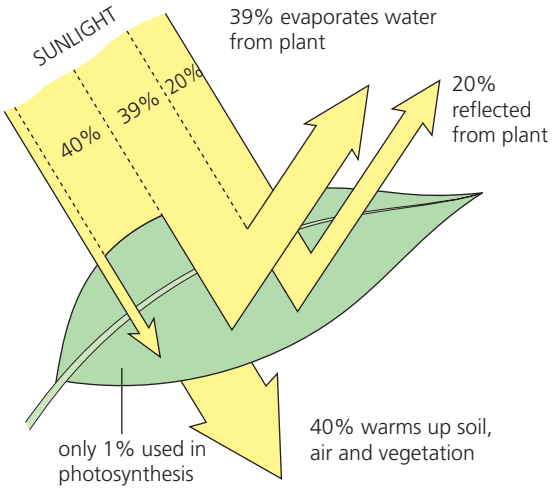
b The hawk had fleas. How would this affect a pyramid of numbers?

c The application of a pesticide killed all the worms. Suggest the effect of this on the food chain.

- 20% is reflected by the vegetation
- 39% is used in evaporating water from the leaves (transpiration)
- 40% warms up the plants, the soil and the air
- about 1% is used in photosynthesis for making new organic matter in the leaves of the plants (Figure 19.8).

This figure of 1% will vary with the type of vegetation and with climatic factors, like availability of water and the soil temperature. Sugar cane grown in ideal conditions can convert 3% of the Sun's energy into photosynthetic products; at the height of its growth, sugar beet is almost 9% efficient.

Crop plants need enough water and mineral ions to be at their most efficient. Irrigation and the use of fertiliser help this.

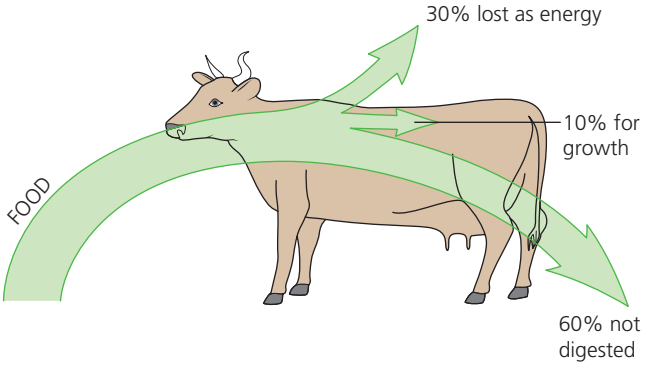


▲ **Figure 19.8** Absorption of Sun's energy by plants

Energy transfer between organisms

Now, we will study the efficiency of energy transfer from plant products to primary consumers. On land, primary consumers only eat a small proportion of the vegetation that is available. In a deciduous forest only about 2% is eaten; in grazing land, 40% of the grass may be eaten by cows. However, in open water, the producers are microscopic plants (phytoplankton, see Figure 19.3(a)). These are swallowed whole by the primary consumers in the zooplankton (see Figure 19.3(b)), and 90% or more may be eaten. In the land communities, the parts of the vegetation not eaten by the primary consumers will eventually die and be used as a source of energy by decomposers.

A cow is a primary consumer; over 60% of the grass it eats passes through its alimentary canal (Chapter 8) without being digested. Another 30% is used in the cow's respiration to provide energy for its movement and other life processes. Less than 10% of the plant material is converted into new animal tissue to contribute to growth (Figure 19.9). This figure will vary with the diet and the age of the animal. In a fully grown animal all the digested food will be used for energy and replacement and none will contribute to growth. Economically it is best to harvest the primary consumers before their rate of growth starts to reduce.



▲ **Figure 19.9** Energy transfer from plants to animals

The transfer of energy from primary to secondary consumers is probably more efficient, because a larger proportion of the animal food is digested and absorbed compared to plant material. The transfer of energy at each stage in a food chain may be shown by classifying the organisms in a **community** by their trophic levels, then showing their relative masses in a pyramid like the one shown in Figure 19.2 but on a more accurate scale (see Figure 19.6).

It is very unusual for food chains to have more than five trophic levels because, on average, about 90% of the energy is lost at each level. As a result, very little of the energy entering the chain through the producer is available to the top consumer. The food chain below shows how the energy reduces through the chain. It is based on grass obtaining 100 units of energy.

grass →	locust →	lizard →	snake →	mongoose
100 units	10 units	1 unit	0.1 unit	0.01 unit

Energy transfer in agriculture

In human communities, the use of plant products to feed animals that provide meat, eggs and dairy products is wasteful. This is because only 10% of the plant material is converted to animal products. It is more economical to eat bread made from the wheat than to feed the wheat to hens and then consume the eggs and chicken meat. This is because eating the

wheat as bread avoids using any part of its energy to keep the chickens alive and active. Energy losses can be reduced by keeping hens indoors in small cages. There, they lose less heat to the atmosphere and cannot use much energy in movement (Figure 19.10). However, many people feel that these methods are not humane, and the energy saving is far less than if the plant products were eaten directly by humans.

▲ **Figure 19.10** Battery chickens. The hens are well fed but kept in crowded and cramped conditions with no opportunity to move about or scratch in the soil as they would normally do

There are other ways energy is wasted in a modern agricultural system. To produce 1 tonne of nitrogenous fertiliser takes the energy equivalent of burning 5 tonnes of coal. Calculations show that if the energy needed to produce the fertiliser is added to the energy used to produce a tractor and to power it, the energy obtained from the food produced is less than that used in producing it.

Nutrient cycles

FOCUS POINTS

- ★ How is carbon cycled?
- ★ What is the nitrogen cycle?
- ★ How are microorganisms involved in the nitrogen cycle?

The carbon cycle

Carbon is an element that occurs in all the compounds that make up living organisms. Plants get their carbon from carbon dioxide in the atmosphere and animals get their carbon from plants. So, the carbon cycle is mainly concerned with what happens to carbon dioxide (Figure 19.11).

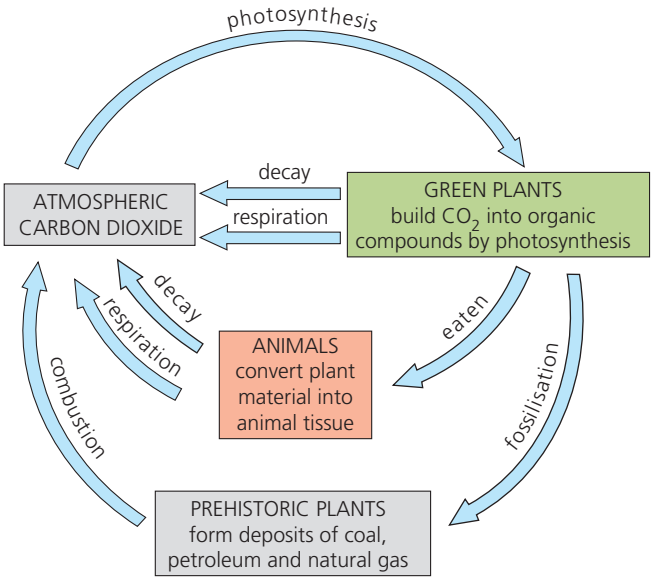
Removal of carbon dioxide from the atmosphere

Photosynthesis

Green plants remove carbon dioxide from the atmosphere as a result of their photosynthesis. The carbon from the carbon dioxide is built first into a carbohydrate such as glucose. Some of this is changed into starch or the cellulose of cell walls, and the proteins, pigments and other compounds of a plant. When the plants are eaten by animals, the organic plant material is digested, absorbed and built into the compounds making up the animals' tissues. In this way, the carbon atoms from the plant become part of the animal.

Test yourself

1 Construct a food web using the following: sparrow, wolf, wheat seeds, cat, kestrel, mouse.
2 Describe briefly all the possible ways in which the following might depend on each other: grass, earthworm, robin, lime tree, soil.
3 Explain how the following foodstuffs are produced as a result of photosynthesis: butter, eggs, beans.
4 An electric motor, a car engine and a racehorse can all release energy. Show how this energy could come, originally, from sunlight.
5 a Study the food web in Figure 19.7. Write out all the food chains involving four or more organisms that you can see in this food web.
b Under each organism, identify its trophic level.
6 When humans colonised islands they often introduced their domestic animals, like goats or cats. This usually had a damaging effect on the natural food webs. Suggest reasons for this.



▲ **Figure 19.11** The carbon cycle

Fossilisation

Any conditions that stop fast **decomposition** may produce fossils. The carbon in the dead organisms becomes trapped and compressed and can remain there for millions of years. The carbon may form **fossil fuels** like coal, oil and natural gas. Some animals make shells or exoskeletons containing carbon and these can become fossils.

Addition of carbon dioxide to the atmosphere

Respiration

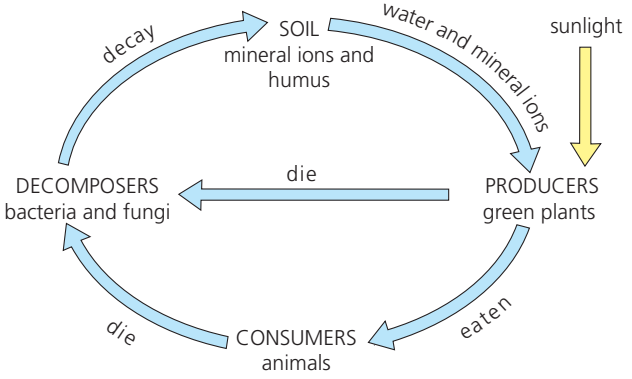
Plants and animals obtain energy by **respiration** using carbohydrates and oxygen in their cells. This process produces carbon dioxide and water (Chapter 10). The carbon dioxide and water are **excreted** so the carbon dioxide returns once again to the atmosphere.

Decomposition

A crucial factor in carbon recycling is the process of decomposition. Decomposition releases essential materials from dead organisms. When an organism dies, the enzymes in its cells are free from normal controls. They start to digest its own tissues (auto-digestion). Soon, scavengers appear on the scene and eat much of the remains; blowfly larvae consume carcases, earthworms eat dead leaves.

Finally, the decomposers, fungi and bacteria (collectively called microorganisms), arrive and invade the remaining tissues (Figure 19.12). These organisms, which feed on dead material (saprophytes), secrete extracellular enzymes (Chapter 5) into the tissues and reabsorb the liquid products of digestion. When the microorganisms themselves die, auto-digestion takes place, releasing the products like nitrates, sulfates, phosphates, etc. into the soil or the surrounding water. They are then taken up again by the producers in the **ecosystem** (Figure 19.13).

▲ **Figure 19.12** Mould fungus growing on over-ripe oranges



▲ **Figure 19.13** Recycling in an ecosystem

The speed of decay depends on the abundance of microorganisms, temperature, the presence of water and, in many cases, oxygen. High temperatures speed up decay because they speed up respiration of the microorganisms. Water is necessary for all living processes and oxygen is needed for aerobic respiration of the bacteria and fungi. Decay can take place in anaerobic conditions, but it is slow and incomplete, as in the water-logged conditions of peat bogs.

Combustion (burning)

When carbon-containing fuels like wood, coal, petroleum and natural gas are burned, the carbon is oxidised to carbon dioxide ($C + O_2 \rightarrow CO_2$). The

hydrocarbon fuels, like coal and petroleum, come from ancient plants. They only partly decomposed over the millions of years since they were buried.

So, an atom of carbon that is in a molecule of carbon dioxide in the air today may be in a molecule of cellulose in the cell wall of a blade of grass tomorrow. When the grass is eaten by a cow, the carbon atom may become part of a glucose molecule in the cow's bloodstream. When the glucose molecule is used for respiration, the carbon atom will be breathed out into the air once again as carbon dioxide.

The same kind of cycling applies to nearly all the elements of the Earth. No new matter is created, but it is rearranged. A large proportion of the atoms of which you are composed will, at one time, have been part of other organisms.

The nitrogen cycle

When a plant or animal dies its tissues **decompose**, partly as a result of the action of saprophytic bacteria. One of the important products of the decay of animal and plant protein is ammonia. Ammonia, NH_3, is a compound of nitrogen. It dissolves readily in water to form ammonium ions (NH_4^+) and is washed into the soil (Figure 19.13).

The excretory products of animals contain nitrogenous waste products like ammonia and urea (Chapter 13). Urea is formed in the liver of humans as a result of deamination. This process involves the removal of the nitrogen-containing part of amino acids (see Chapter 13). The organic matter in animal droppings is also decomposed by soil bacteria.

Processes that add nitrates to soil

Nitrifying bacteria

These are bacteria living in the soil, which use the ammonia from excretory products and decaying organisms as a source of energy (as we use glucose in respiration). In the process of getting energy from ammonia, called **nitrification**, the bacteria produce nitrates.

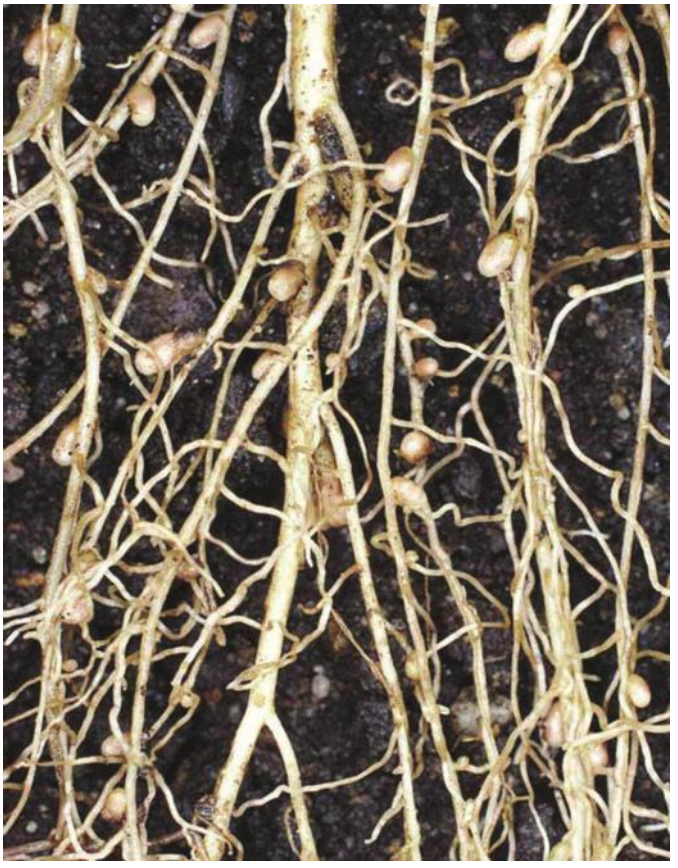
- The nitrite bacteria oxidise ammonium compounds to nitrites ($NH_4^+ \rightarrow NO_2^-$).
- Nitrate bacteria oxidise nitrites to nitrates ($NO_2^- \rightarrow NO_3^-$).

Although plant roots can take up ammonia in the form of its compounds, they take up nitrates more readily, so the nitrifying bacteria increase the fertility of the soil by making nitrates available to the plants.

Nitrogen-fixing bacteria

This is a special group of nitrifying bacteria that can absorb nitrogen as a gas from the air spaces in the soil and build it into compounds of ammonia. Plants cannot use nitrogen gas. However, when it has been made into a compound of ammonia, it can easily be changed to nitrates by other nitrifying bacteria. The process of building the gas, nitrogen, into compounds of ammonia is called nitrogen fixation.

Some of the nitrogen-fixing bacteria live freely in the soil. Others live in the roots of leguminous plants (peas, beans, clover), where they cause swellings called root nodules (Figure 19.14). These leguminous plants can thrive in soils where nitrates are limited, because the nitrogen-fixing bacteria in their nodules make compounds of nitrogen available for them.



▲ **Figure 19.14** Root nodules of white clover – a leguminous plant

Leguminous plants are also included in crop rotations to increase the nitrate content of the soil.

Lightning

The high temperature of lightning discharge causes some of the nitrogen and oxygen in the air to combine and form oxides of nitrogen. These dissolve in the rain and are washed into the soil as weak acids, where they form nitrates. Although several million tonnes of nitrate may reach the Earth's surface in this way each year, this forms only a small fraction of the total nitrogen being recycled.

Processes that remove nitrates from the soil

Uptake by plants

Plant roots absorb nitrates from the soil and combine them with carbohydrates to make amino acids, which are built up into proteins (Chapter 6). These proteins are then available to animals, which feed on the plants and digest the proteins in them.

Going further

Leaching

Nitrates are very soluble (i.e. dissolve easily in water), and as rainwater passes through the soil it dissolves the nitrates and carries them away in the run-off or to deeper layers of the soil. This is called leaching. (See pages 349 and 350 for some of the implications of leaching.)

Denitrifying bacteria

Denitrifying bacteria obtain their energy by breaking down nitrates to nitrogen gas, which then escapes from the soil into the atmosphere. This process is called **denitrification**.

All of these processes are summed up in Figure 19.15.

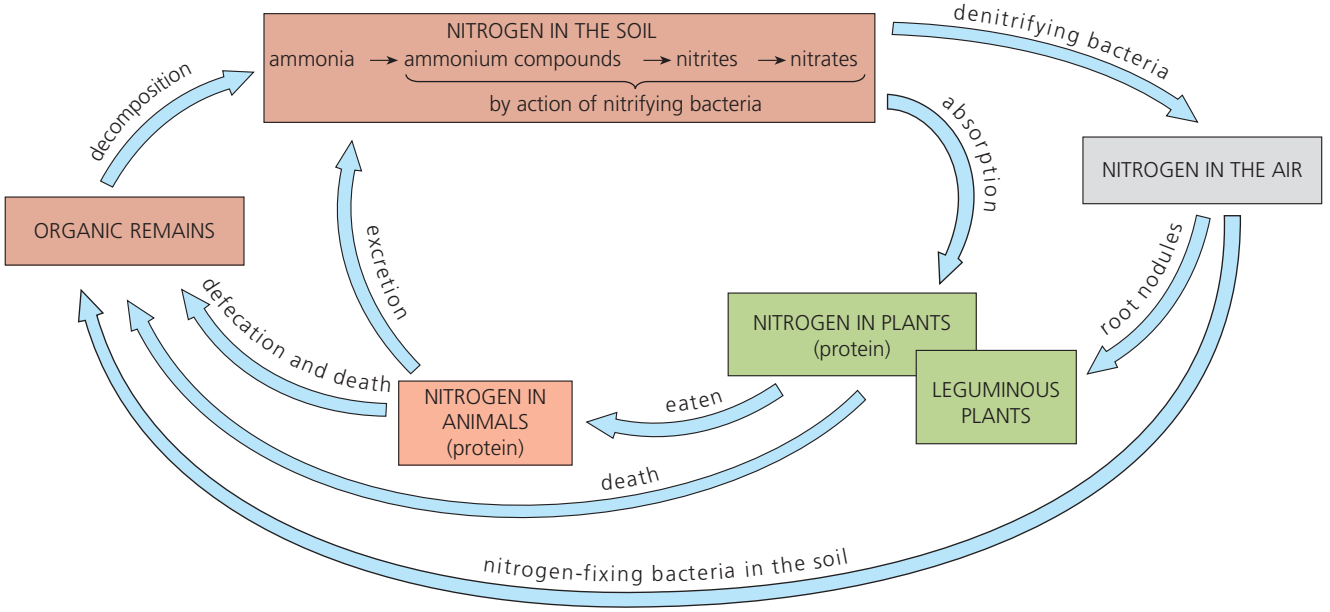
Test yourself

7 a Why do living organisms need a supply of carbon?
  b Give three examples of carbon-containing compounds that occur in living organisms (see Chapter 4).
  c Where do the following organisms get their carbon from:
    i) animals
    ii) plants?

8 Write three chemical equations to show that
  a respiration produces carbon dioxide (see Chapter 10)
  b burning produces carbon dioxide
  c photosynthesis uses up carbon dioxide (see Chapter 6).

9 On a lawn growing on nitrate-deficient soil, the patches of clover often stand out as dark green and healthy against a background of pale green grass. Suggest a reason for this difference.

10 Outline the differences between nitrifying, nitrogen-fixing and denitrifying bacteria.



▲ **Figure 19.15** The nitrogen cycle

Populations

FOCUS POINTS

- ★ What is a population, community and ecosystem?
- ★ What is biodiversity?
- ★ What factors affect the rate of population growth of an organism?
- ★ What is the effect of human population growth on global resources?

Key definitions

A **population** is a group of organisms of one species, living in the same area, at the same time.

A **community** is all the populations of different species in an ecosystem.

An **ecosystem** is a unit containing the community of organisms and their environment, interacting together.

Populations

In biology, the term population always refers to a single species. A biologist might refer to the population of sparrows in a farmyard or the population of catfish in a lake. In each case this would mean the total numbers of sparrows or the total numbers of catfish in the stated area.

Communities

A community is made up of all populations of plant and animal species living in an ecosystem. In the soil there is a community of organisms, which includes earthworms, springtails and other insects, mites, fungi and bacteria. In a lake, the animal community will include fish, amphibians, insects, crustacea and Protoctista. The plant community will consist of rooted plants with submerged leaves, rooted plants with floating leaves, reed-like plants growing at the edge of the lake, plants floating freely on the surface, filamentous algae and single-celled algae in the surface waters.

Ecosystems

The community of organisms in a habitat, plus the non-living part of the environment (air, water, soil, light, etc.) make up an ecosystem. A lake is an ecosystem, which consists of the plant and animal communities mentioned above, and the water, mineral ions, dissolved oxygen, soil and sunlight on which they depend. An ecosystem is self-supporting (Figure 19.16).

▲ **Figure 19.16** An ecosphere. The 5-inch globe contains seawater, bacteria, algae, snails and a few Pacific shrimps. Given a source of light it is a self-supporting system and survives for several years (at least). The shrimps live for up to 7 years, but few reproduce

In a woodland ecosystem, the plants absorb light and rainwater for photosynthesis, the animals feed on the plants and on each other. The dead remains of animals and plants, used as food by fungi and bacteria, return nutrients to the soil.

Lakes and ponds are good examples of ecosystems. Sunlight, water and mineral ions allow the plants to grow and support animal life. The recycling of materials from the dead organisms keeps the supply of nutrients.

So, a *population* of catfish forms part of the animal *community* living in a *habitat* called a lake. The communities in this habitat, together with their watery *environment*, make up a self-supporting *ecosystem*.

individuals of the same species = POPULATION + populations of other species = COMMUNITY

COMMUNITY + non-living part of environment = ECOSYSTEM

A catfish is a *secondary consumer* at the top of a *food chain*, where it is in *competition* with other species of fish for food and with other catfish for food and mates.

The whole of the part of the Earth's surface that contains living organisms (called the biosphere) may be seen as one huge ecosystem.

No new material (in significant amounts) enters the Earth's ecosystem from space and there is no significant loss of materials. The whole system depends on a constant input of energy from the Sun and recycling of the chemical elements.

Distribution in an ecosystem

All ecosystems contain producers, consumers and decomposers. The organisms are not spread evenly throughout the ecosystem but live in habitats that suit their way of life.

For example, fish may swim freely within an aquatic ecosystem but most of them will have preferred habitats in which they feed and spend most of their time. Rays and flatfish feed on molluscs and worms on the sea floor, whereas sardines and Indian mackerel feed on plankton and small fish in the surface waters. In a pond, the snails do not move much from the plants on which they feed. On a rocky coast, limpets and barnacles can resist exposure between the tides and colonise the rocks. Some seaweeds cannot cope with being out of water and are restricted mainly to the rocky pools left at low tide, or to the sea beyond the low tide mark.

Factors affecting population growth

A population grows when the birth rate exceeds the death rate.

Food supply

If conditions are ideal, a population can increase in size. For this to happen there needs to be a good food supply. This will allow organisms to breed more successfully to produce more offspring; shortage of food can result in starvation, leading to death. It can also force emigration, reducing the population. The food shortage may be because the food source has all been eaten, has died out, or has completed its growing season.

Competition

Within a habitat there will be competition for factors such as food and shelter. This competition may be between individuals of the same species, or between individuals of different species if they eat the same food. There will also be competition within a species for mates.

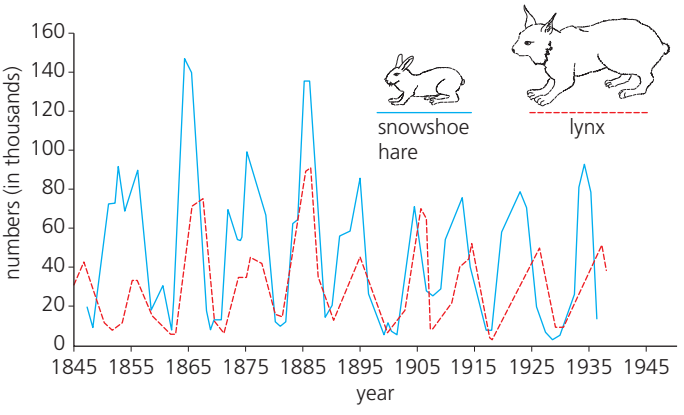
Predator–prey relationships

In a habitat there are likely to be predators. If heavy predation of a population happens, the rate of breeding may be unable to produce enough organisms to replace those eaten, so the population will drop in numbers. There tends to be a time lag in population size change for predators and their prey: as predator numbers increase, prey numbers drop and as predator numbers drop, prey numbers rise again (unless there are other factors that prevent this happening).

A classic example of predator–prey relationships comes from an analysis of the fluctuating populations of lynxes and snowshoe hares in Canada. The figures are worked out from the numbers of skins sold by trappers to the Hudson's Bay Company between 1845 and 1945.

The lynx preys on the snowshoe hare, and the most likely explanation of the graph in Figure 19.17 is that an increase in the hare population allowed the predators to increase. Eventually the increasing numbers of lynxes caused a reduction in the hare population.

However, seasonal or other changes affecting one or both of the animals could not be ruled out.



▲ **Figure 19.17** Predator–prey relationships: fluctuations in the numbers of pelts received by the Hudson's Bay Company for lynx (predator) and snowshoe hare (prey) over a 100-year period

Disease

Disease can be a special problem in large populations because it can spread easily from one individual to another. Epidemics can reduce population sizes very rapidly. For example, olive trees are being killed by a bacterial pathogen, *Xylella fastidiosa*. The disease was first detected in 2013 when an outbreak hit olive plantations in southern

Italy. It has reduced the olive crop by 60% in some places, as mature trees have been killed by the bacterium. Banana growers have been affected by a similar problem, but it is caused by a fungus which makes the plants wilt. Fungal diseases are often treatable, but this one is resistant to fungicides. The most popular variety of banana, Cavendish, is under threat because of the infection. The fungus has already forced banana growers to switch from another banana variety because the fungus destroyed whole plantations.

When a disease spreads globally it is called a pandemic. In 2020 and 2021, one of the worst cases experienced by humans was the virus causing COVID-19 disease. This was a virus new to science and it is especially infectious. It takes time to develop an effective vaccine and equip hospitals with suitable equipment to support patients and protect staff. HIV continues to be a huge problem around the world, with 37.9 million people infected and an estimated 770 000 deaths in 2018 (World Health Organization statistics). Drugs are being developed to treat people with the infection and 60% of the world population infected by the virus are now receiving effective medication.

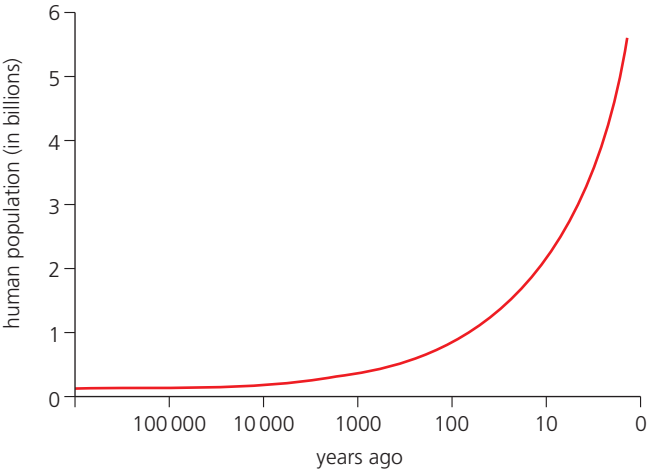
The World Health Organization (WHO) estimates that there were 405 000 malaria deaths in 2018 and there were about 228 million cases of the disease. Malaria is caused by a single-celled parasite spread by mosquitoes. It is a treatable disease and drugs are gradually becoming more widely available to prevent it being fatal.

Human population

In 1000AD, the world population was probably about 300 million. In the early 19th century it rose to 1 000 million (1 billion), and by 1984 it had reached 4.7 billion. In 2 000 it reached about 6 billion and rose to 7.7 billion in 2019. The United Nations predicts that the global population will increase steadily by 2050, quoting predictions of between 8.3 and 10.9 billion people by that date. The graph in Figure 19.18 shows that the greatest population surge has taken place in the last 300 years.

Population growth

About 20 years ago, the human population was increasing at the rate of 2% a year. This may not sound very much, but it means that the world population was doubling every 35 years. This doubles the demand for food, water, space and other resources. Recently, the growth rate has slowed to 1%. However, it is not the same everywhere. South Sudan's population is growing by 3.8% each year, but India's grows at 1.0%.



▲ **Figure 19.18** World population growth. The time scale (horizontal axis) is logarithmic. The right-hand space (0–10) represents only 10 years, but the left-hand space (100 000 to 1 million) represents 900 000 years. The greatest population growth has taken place in the last 300 years

Usually, we assume that population growth is limited by famine, disease or war. These factors are affecting local populations in some parts of the world today, but they are unlikely to have a limiting effect on the rate of overall population growth.

Diseases like malaria and sleeping sickness (spread by tsetse flies) have limited the spread of people into affected areas for many years.

Diseases like bubonic plague and influenza have cut population growth from time to time, and the current AIDS epidemic in sub-Saharan Africa is having significant effects on population growth and life expectancy.

Factors affecting population growth

If a population is to grow, the birth rate must be higher than the death rate. Suppose a population of 1 000 people produces 100 babies each year but only 50 people die each year. This means that 50 new individuals are added to the population each year and the population will double in 20 years (or less if the new individuals start reproducing at 16).

One of the factors affecting population growth is infant mortality, i.e. the death rate for children less than 1 year old. Populations in the newly industrialising

world are growing, not because of an increase in the number of babies born per family, but because more babies are surviving to reach reproductive age. Infant mortality is falling and more people are living longer. So, life expectancy is increasing.

Factors affecting the increase in size of the human population

Increase in life expectancy

The life expectancy is the average age to which a newborn baby can be expected to live. In Europe between 1830 and 1900 the life expectancy was 40–50 years. Between 1900 and 1950 it rose to 65 and it now stands at 79–84 years. In sub-Saharan Africa, life expectancy was rising to 58 years until the AIDS epidemic reduced it to about 45 years. It is now about 61 years, due to improvements in **nutrition** and access to water and HIV medication. Japan has the highest life expectancy, at 84 years.

These figures are averages. They do not mean, for example, that everyone in the developing world will live to the age of 58. In the newly industrialising world, 40% of the deaths are of children younger than 5 years and only 25–30% are deaths of people over 60. In Europe, only 5–20% of deaths are those of children below the age of 5, but 70–80% are of people over 60.

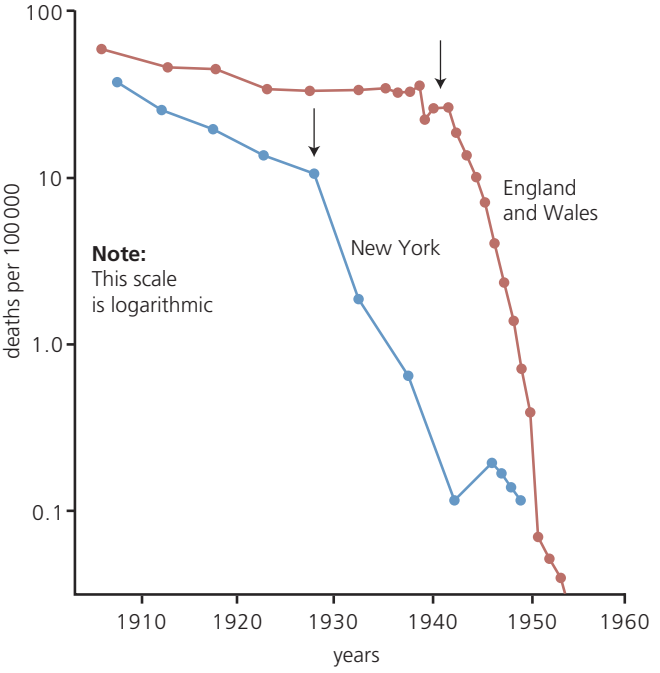
An increase in the number of people over the age of 60 does not change the rate of population growth much, because these people are past child-bearing age. On the other hand, if the death rate among children falls and the extra children survive to reproduce, the population will continue to grow. This is the main reason for the rapid population growth in the newly industrialising world since 1950.

Causes of the reduction in death rate

The causes are not always easy to identify and vary from one community to the next. In 19th century Europe, agricultural development and economic expansion led to improvements in nutrition, housing and sanitation, and to clean water supplies. These improvements reduced the frequency of infectious diseases in the general population, and better-fed children could resist these infections when they did meet them. The drop in deaths from infectious diseases probably accounted for three-quarters of the total fall in deaths.

The social changes probably affected the population growth more than the discovery of new drugs or improved medical techniques did. Because of these techniques – particularly immunisation – diphtheria, tuberculosis and polio are now rare (Figure 19.19), and by 1977 smallpox had been wiped out by the World Health Organization's vaccination campaign.

In the developing world, sanitation, clean water supplies and nutrition are improving slowly. The surge in the population since 1950 is likely to be at least 50% due to modern drugs, vaccines and insecticides.



▲ **Figure 19.19** Fall in death rate from diphtheria as a result of immunisation. The arrows show when 50% or more of children were vaccinated. **Note:** The rate was already falling but was greatly increased by immunisation

Stability and growth

Up to 300 years ago, the world population was quite stable. Fertility (the birth rate) was high, but so was the mortality rate (death rate). Probably less than half the children born lived to have children of their own. Many died in their first year (infant mortality), and many mothers died during childbirth.

No one saw any point in reducing the birth rate. If you had a lot of children, you had more help on your land and a better chance that some of them would live long enough to care for you in your old age.

In the past 300 years, the mortality rate has fallen but the birth rate has not gone down as much. As a result, the population has expanded rapidly.

A fall in the fertility rate means that young people will form a smaller proportion of the population. There will also be an increasing proportion of old people for the younger generation to look after.

In the newly industrialising world, the fertility rate has dropped from about 6.2 to 3.0. This is still higher than the mortality rate. An average fertility rate of 2.1 is necessary to keep the population stable.

As a community grows wealthier, the birth rate goes down. There are believed to be four reasons:

- **Longer and better education:** marriage is postponed, and a better-educated couple will have learned about methods of family limitation.
- **Better living conditions:** once people realise that half their offspring are not going to die from disease or malnutrition, family sizes fall.
- **Agriculture and cities:** modern agriculture is no longer labour intensive. Farmers do not need large families to work on the land. City dwellers do not depend on their offspring to help raise crops or herd animals.
- **Application of family planning methods:** either natural methods of birth control or the use of contraceptives is much more common.

It takes many years for social improvements to produce a fall in the birth rate. Some countries are trying to speed up the process by encouraging couples to limit their family size (Figure 19.20), or by penalising families who have too many children.

Meanwhile the population goes on growing. At present it is estimated to be 7.6 billion. The United Nations expect that the birth rate and death rate will not be in balance until the year 2100. By that time the world population may have reached 11.2 billion, assuming that the world supply of food will be able to feed this population.

In the past few decades, the world has produced enough food to feed, in theory, all the extra people. But the extra food and the extra people are not always in the same place. As a result, 72% of the world's population has a diet that lacks energy, as well as other nutrients.

Every year between 1965 and 1975, food production in the industrialised nations rose by 2.8%, while the population rose by 0.7%. In the emerging nations during the same period, food production rose by only 1.5% each year, while the annual population rise was 2.4%.

The Western world can produce more food than its people can consume. Meanwhile people in the drier regions of Africa face famine due to drought and population pressure on the environment. Even if the food could be taken to the newly industrialising world, people there are often too poor to buy it. Ideally, each region needs to grow more food or reduce its population until the community is self-supporting. Some countries grow tobacco, cotton, tea and coffee (cash crops) in order to get foreign currency for imports from the Western world. This is fine, so long as they can also feed their people. But when food is scarce, people cannot live on the cash crops.

Population pressures

More people, more agriculture and more industrialisation will put still more pressure on the environment unless we are very alert. If we damage the ozone layer, increase atmospheric carbon dioxide, release radioactive products or allow farmland to erode, we may face extra limits to population growth.

The demand for global resources

As the human population increases, so does the demand for global resources. This includes not only food, but fuel, materials for construction such as sand, gravel and limestone, and metals. Recycling is becoming more important to satisfy some of the increases in demand for materials. As the demand for land for building or agriculture increases, natural habitats are being removed.

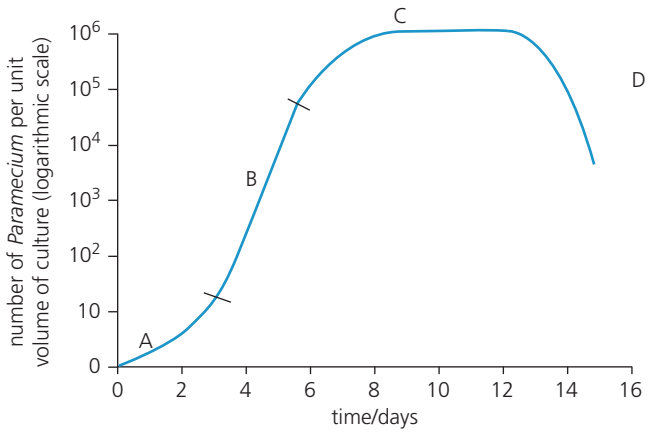
▲ **Figure 19.20** Family planning. A health worker in Bangladesh explains the use of a condom

Going further

Sigmoid population growth curves

Population growth

A population will not always be evenly spread throughout its habitat, and its numbers may not remain steady. The population will also be made up of a wide variety of individuals: adults (male and female), juveniles, larvae, eggs or seeds, for example. In studying populations, these variables often must be simplified.



▲ **Figure 19.21** The sigmoid curve (*Paramecium caudatum*). This is the characteristic growth pattern of a population when there is plenty of food at first

In the simplest case, where a single species is allowed to grow in laboratory conditions, the population may develop as shown in Figure 19.21.

The population might be of yeast cells growing in a sugar solution, flour beetles in wholemeal flour or weevils in a grain store. The curve shown in Figure 19.21 was obtained using a single-celled organism called *Paramecium* (see Chapter 2), which reproduces by dividing into two (binary fission).

The sigmoid (S-shaped) form of the graph can be explained as follows:

- **A: Lag phase.** The population is small. Although the numbers double at each generation, this does not result in a large increase.
- **B: Exponential phase (log phase).** Continued doubling of the population at each generation produces a logarithmic growth rate (e.g. 64 – 128 – 256 – 512 – 1 024). When a population of four doubles, it is not likely to strain the resources of the habitat, but when a population of 1 024 doubles there is likely to be far more competition for food and space, and so the growth rate starts to slow down.
- **C: Stationary phase.** The resources are not enough to support an increasing population. At this stage, limiting factors come into play. The food supply may limit further expansion of the population, diseases may start to spread through the dense population and overcrowding may lead to a fall in reproduction rate. Now the mortality rate (death rate) equals the reproduction rate, so the population numbers stay the same.
- **D: Death phase.** The mortality rate (death rate) is now greater than the reproduction rate, so the population numbers begin to drop. Fewer offspring will live long enough to reproduce. The drop in population numbers can happen because there is not enough food, waste products contaminate the habitat or disease spreads through the population.

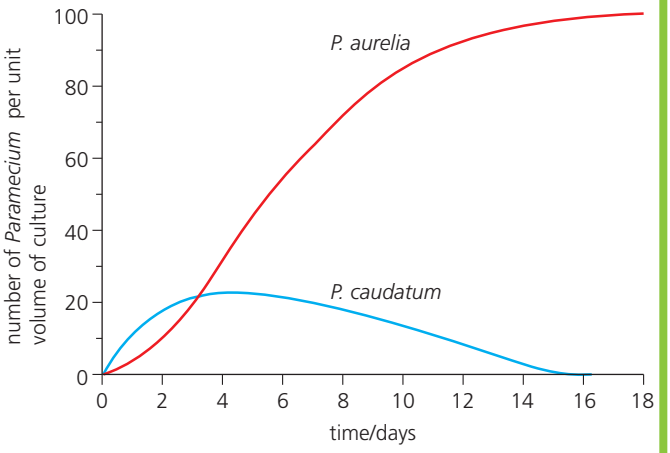
Limits to population growth

The sigmoid curve is a very simplified model of population growth. Few organisms occupy a habitat on their own, and the conditions in a natural habitat will be changing all the time. The steady state of the population in part C of the sigmoid curve is hardly ever reached in nature. In fact, the population is unlikely to reach its maximum theoretical level because of all the factors limiting its growth. These are called limiting factors.

Competition

If, in the laboratory, two species of *Paramecium* (*P. aurelia* and *P. caudatum*) are placed in an aquarium tank, the population growth of *P. aurelia* follows the sigmoid curve but the population of *P. caudatum* soon drops to zero because *P. aurelia* takes up food more rapidly than *P. caudatum* (Figure 19.22).

This example of competition for food is only one of many factors in a natural environment that will limit a population or cause it to change.



▲ **Figure 19.22** The effect of competition. *Paramecium aurelia* and *P. caudatum* eat the same food but *P. aurelia* can capture and ingest it faster than *P. caudatum*

Abiotic and biotic limiting factors

Plant populations will be affected by non-biological (abiotic) factors like rainfall, temperature and light intensity. Biological (biotic) factors affecting plants include their leaves being eaten by grazing animals or by caterpillars and other insects, and the spread of fungal diseases.

Animal populations, too, will be limited by abiotic factors like seasonal changes. A cold winter can severely reduce the populations of small birds. However, animal populations are also greatly affected by biotic factors like the availability of food, competition for nest sites (Figure 19.23), predation (i.e. being eaten by other animals), parasitism and diseases.

The size of an animal population will also be affected by the numbers of animals moving in from other places (immigration) or leaving the population (emigration).

In a natural environment, it is difficult to say whether the fluctuations seen in a population are mainly due to one particular factor because there are so many factors at work. However, in some cases, the key factors can be identified as mainly responsible for limiting the population.

▲ **Figure 19.23** A colony of nesting gannets. Availability of suitable nest sites is one of the factors that limits the population

Test yourself

11 Define the term *population*.
12 State three factors that can limit the growth of a population.
13 If there are 12 000 live births in a population of 400 000 in 1 year, calculate the birth rate per 1 000.
14 **a** Describe what makes up an ecosystem.
b Explain the difference between a population and a community.

Effects of humans on ecosystems

FOCUS POINTS

- ★ What are the negative effects of deforestation?
- ★ What effects are humans having on habitats and biodiversity?
- ★ What impact do humans have through overharvesting and through introduction of foreign species to a habitat?

Key definitions

Biodiversity is the number of different species that live in an area.

Food chains and food webs

Any form of habitat destruction by humans, even where a single species is wiped out, can have an impact on food chains and food webs. This is because other organisms will use that species as a food source, and so then their numbers will decline. If the species that has disappeared is a predator and was controlling the numbers of other species, the other species will no longer be controlled. It is not always the direct destruction of a habitat that can cause the disruption of food chains and, eventually, damage to the habitat.

For example, on the island of Guam, which lies in the Western Pacific Ocean to the east of the Philippines, there was an accidental introduction of the predatory brown tree snake. The snake wiped out 10 of the 12 native bird species on the island. The birds played an important part in tree pollination, seed germination and seed dispersal, so the forest habitat was also damaged.

The effects of overharvesting

Overharvesting causes the reduction in numbers of a species to the point where it is endangered or made extinct. As a result, biodiversity is affected. The species may be harvested for food, or for body parts such as tusks (elephants), horns (rhinos – Figure 19.24), bones and fur

(tigers), or for selling as pets (reptiles, birds and fish, etc.). In parts of Africa, bush meat is used widely as a source of food. Bush meat is the flesh of primates, such as monkeys. However, hunting these animals is not always regulated or controlled and rare species can be threatened as a result of indiscriminate killing.

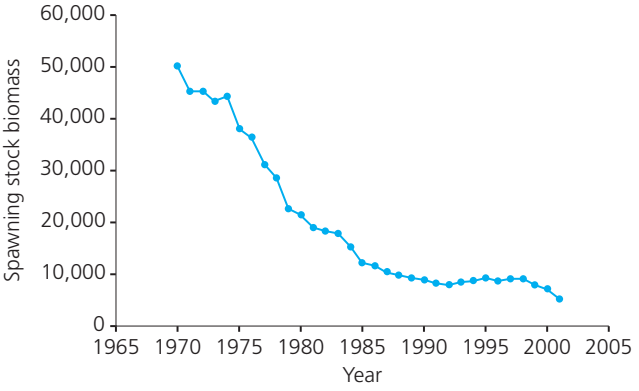
▲ **Figure 19.24** The rhinoceros is endangered. Some people believe that powdered rhino horn (*Cornu Rhinoceri Asiatici*) is a medicine. This is not true. Others like rhino horn handles for their daggers

Overfishing

Humans taking small numbers of fish from lakes or oceans and using simple methods of capture had little effect on fish numbers. However, commercial fishing has increased. Now some fish stocks are threatened and can no longer sustain fishing. In the past 100 years, fishing fleets have increased and the catching methods have become more advanced.

If the number of fish removed from a population is higher than the number of young fish reaching maturity, then the population will fall (Figure 19.25).

At first, the catch size remains the same, but it takes longer to catch it. Then the catch has a greater number of small fish. The return per day at sea goes down even more. Eventually the stocks are so low that it is no longer economical to fish them. The costs of the boats, the fuel and the wages of the crew are more than the value of the catch. Men have no work and the boats are not used. The economy of the fishing village is destroyed. Overfishing has severely reduced stocks of many fish species: herring in the North Sea, halibut in the Pacific and anchovies off the Peruvian coast, for example. The bluefin tuna stocks in the Atlantic have fallen dangerously low, to the point where the future of the species is uncertain. In 1965 1.3 million tonnes of herring were caught in the North Sea. By 1977 the catch had reduced to 44 000 tonnes, i.e. about 3% of the 1965 catch.



▲ **Figure 19.25** Effects of overfishing on bluefin tuna stocks from 1970–2002

Whaling has reduced the population of many whale species to worrying levels. Whales were the first marine organisms to face extinction through overfishing. This happened in the early 1800s when they were killed for their blubber (a thick fat layer around the body of the mammal) for use as lamp oil. The blue whale's numbers have been reduced from about 2 million to below 25 000 as a result of intensive hunting.

Overfishing can reduce the populations of fish species and can also do great damage to the environment where they live. For example, the use of heavy nets dragged along the sea floor to catch the fish can wreck coral reefs, destroying the habitats of many other animal species. Even if the reef is not damaged, fishing for the top predators, such as grouper fish, has a direct effect on the food chain. Fish lower down the chain increase in numbers and overgraze on the reef. This process is happening on the Great Barrier Reef in Australia. Grouper fish are very slow growing and take a long time to become sexually mature, so the chances of them recovering from overfishing are low and they are becoming endangered.

Introducing non-native species to a habitat

An early example of this was an accident. Pirates or whalers in the 17th or 18th centuries introduced rats to the Galapagos Islands. The rats had no natural

predators and there was a lot of food. They fed on the eggs of birds, tortoises and other reptiles, along with young animals. The Galapagos Islands provide a habitat for many rare species. These became endangered because of the rats. A programme of rat extermination is now being carried out on the islands to protect the species that live there.

The prickly pear cactus, *Opuntia*, was introduced to Australia in 1839. It was used as a living fence to control the movement of cattle. However, growth got out of control because of the lack of herbivores that eat it. Millions of acres of land became unusable. The young of a moth, *Cactoblastis cactorum*, feed on the cactus. This moth was introduced from Argentina and helped to control the spread of the cactus. Other places with similar problems, for example, the island of Nevis in the West Indies, followed Australia's example, but did not have good results. The moth had no natural predators and ate other native cactus species as well as the prickly pear. The other cactus species are near extinction. The moth is now spreading to parts of the United States of America and poses a threat to other cactus species.

The use of pesticides and other poisons can also disrupt food chains and webs. Sometimes humans release them into the environment by accident.

The undesirable effects of deforestation on the environment

The removal of large numbers of trees result in habitat destruction on a massive scale.

- Animals living in the forest lose their homes and sources of food; species of plant become extinct as the land is used for other purposes like agriculture, mining, housing and roads. Consequently there is reduced biodiversity.
- Soil erosion is more likely to happen as there are no roots to hold the soil in place. The soil can end up in rivers and lakes, destroying habitats there.
- Flooding becomes more frequent as there is no soil to absorb and hold rainwater. Plant roots rot and animals drown, destroying food chains and webs.
- Carbon dioxide builds up in the atmosphere as there are fewer trees to photosynthesise, increasing global warming. Climate change affects habitats.

Forests have a great effect on climate, water supply and soil maintenance. They have been described as environmental buffers. For example, they capture heavy rainfall. The forests release the water steadily and slowly to the soil and to the streams and rivers that start in or flow through them. The tree roots hold the soil in place.

At present, we are destroying forests, particularly tropical forests, at a rapid rate

1. for their timber
2. to make way for agriculture, roads (Figure 19.26) and settlements
3. for firewood.

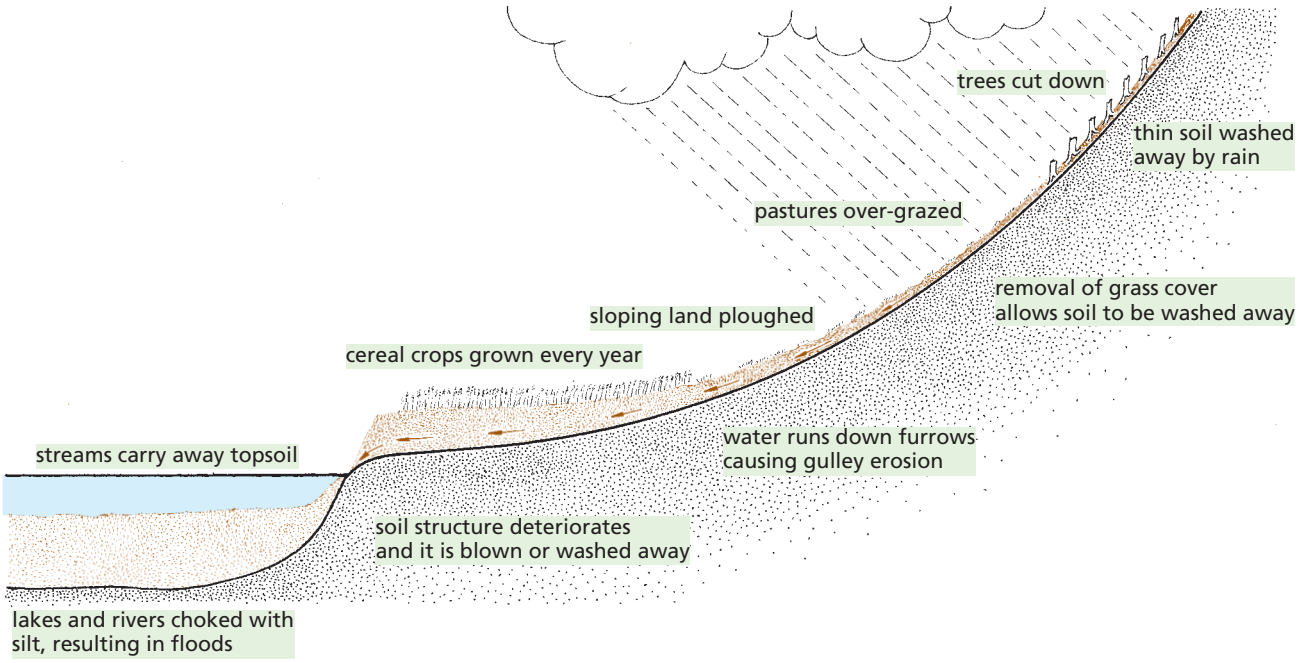
The Global Forest Resources Assessment (FRA) is coordinated by The Food and Agriculture Organisation. It reported that the world's forest area decreased from 31.6% of the global land area to 30.6% between 1990 and 2015. However, it did note that the pace of loss has slowed down more recently. Some countries are affected more seriously than others. The World Wide Fund for Nature identifies the Amazon basin as the biggest deforestation front in the world. It estimates that 27% of the Amazon will be without trees by 2030 if the present rate of deforestation continues. This will have a severe impact on biodiversity because it is home to about 10% of all the known species of animals and plants on Earth.

Removal of forests allows soil erosion, silting up of lakes and rivers, floods and the permanent loss of thousands of species of animals and plants.

Trees can grow on hillsides even when the soil layer is quite thin. However, when the trees are cut down and the soil is ploughed, there is less protection from the wind and rain. Heavy rainfall washes the soil off the hillsides into the rivers. The hillsides are left bare and useless. The rivers become choked up with mud and silt, which can cause floods (Figures 19.27 and 19.28). For example, Argentina spends 10 million dollars a year on dredging silt from the River Plate estuary to keep the port of Buenos Aires open to shipping. Eighty per cent of this sediment comes from a deforested and overgrazed region 1 800 km upstream. This is only 4% of the river's total catchment area. Sediment has halved the lives of reservoirs, hydroelectric schemes and irrigation programmes. The disastrous floods in India and Bangladesh in recent years may be due largely to deforestation.

▲ **Figure 19.26** Cutting a road through a tropical rainforest. The road not only destroys the natural vegetation, it also opens up the forest to further exploitation

▲ **Figure 19.27** Soil erosion. Removal of forest trees from steeply sloping ground has allowed the rain to wash away the topsoil



▲ **Figure 19.28** The causes of soil erosion

The soil of tropical forests is usually very poor in nutrients. Most of the organic matter is in the leafy canopy of the tree tops. For a year or two after felling and burning, the forest soil produces good crops, but the nutrients are soon used up and the soil eroded. The agricultural benefit from cutting down forests is very short-lived, and the forest does not recover even if the land is abandoned.

Forests and climate

About half the rain that falls in tropical forests comes from the transpiration of the trees themselves. The clouds that form from this transpired water help to reflect sunlight. This keeps the region relatively cool and humid. When areas of forest are cleared, this source of rain is removed,

cloud cover is reduced and the local climate changes quite dramatically. The temperature range from day to night is more extreme and the rainfall reduces.

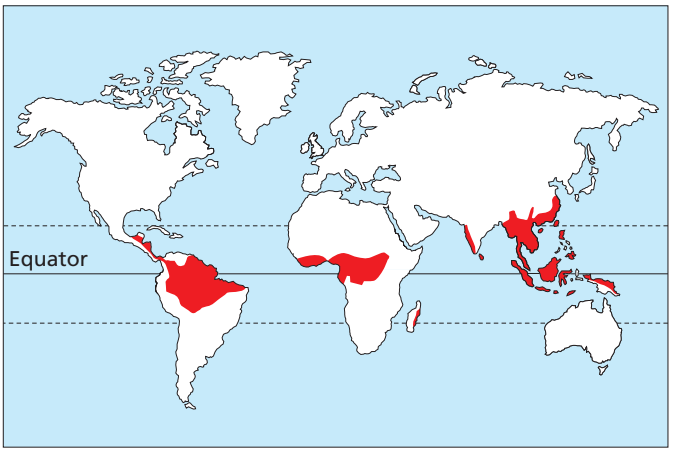
In North-Eastern Brazil, for example, deforestation has nearly reached 60%. If more than 60% of a forest is cleared, it may cause permanent changes in the climate of the whole region. This could turn the region into an unproductive desert.

Removal of trees on such a large scale also reduces the amount of carbon dioxide removed from the atmosphere in the process of photosynthesis (see 'Nutrient cycles' in this chapter and 'Photosynthesis' in Chapter 6). This all adds to the amount of carbon dioxide in the atmosphere. Most scientists agree that the build-up of CO_2 in the atmosphere contributes to global warming.

Forests and biodiversity

One of the most important features of tropical rainforests is the enormous diversity of species they contain. A pine wood or forest may consist of only one or two species of tree. In a rainforest in Borneo there are about 3 000 species of tree and they are widely spread throughout the habitat. It follows that there is also a wide diversity of animals that live in habitats like these (over 1 000 species in Borneo). In fact, it has been estimated that half of the world's 10 million species live in tropical forests.

So, destruction of tropical forest destroys a large number of different species. This is driving many of them to the edge of **extinction**. It also drives out the local populations of humans. We may be depriving ourselves of many valuable sources of chemical compounds that the plants and animals produce. The US National Cancer Institute has identified 3 000 plants that have products active against cancer cells and 70% of them come from rainforests (Figure 19.29).



▲ **Figure 19.29** The world's rainforests

Test yourself

15 State in what ways trees protect the soil on a hillside from being washed away by the rain.
16 If a farmer ploughs a steeply sloping field, suggest in what direction the furrows should run to help cut down soil erosion.
17 Suggest the possible connection between
   a cutting down trees on hillsides and flooding in the valleys
   b clear-felling (logging) in tropical forests and local climate change.
18 State what kinds of human activity can lead to the extinction of a species.

Going further

Removal of habitats

Farmland is not a natural habitat but, at one time, hedgerows, hay meadows and stubble fields were important habitats for plants and animals. Hay meadows and hedgerows supported a wide range of wild plants. They also provided feeding and nesting sites for birds and animals.

Intensive agriculture has destroyed many of these habitats. Hedges have been taken out to make fields larger. A monoculture of grasses to feed farm animals (Figure 19.30) has replaced the mixed population of a hay meadow (Figure 19.31). Planting winter wheat has prevented animals getting access to stubble fields in autumn. As a result, populations of butterflies, flowers and birds have fallen.

In some countries laws prohibit the removal of hedgerows without approval, but the only hedges protected in this way are those considered to be important because of species diversity or historical significance.

Advice to farmers on how to manage their land in ways that encourage wildlife includes, for example, leaving strips of uncultivated land around the edges of fields or planting new hedgerows. Even strips of wild grasses and flowers between fields significantly increase the population of useful insects.

The development of towns and cities (urbanisation) makes a big demand on land, destroying natural habitats.

▲ **Figure 19.30** Grass for animal feed. There is no variety of plant life, and so little to support populations of insects and other animals

▲ **Figure 19.31** The variety of wild flowers in a traditional hay meadow will attract butterflies and other insects

Extraction of natural resources

An increasing population and greater demands on modern technology means we need more raw materials for the manufacturing industry and greater energy supplies.

Fossil fuels like coal can be mined, but this can permanently damage habitats. This is due to the process of extraction and also dumping the rock extracted in spoil heaps. Some methods of coal extraction involve scraping off existing soil from the surface of the land. Spoil heaps created from waste rock can contain toxic metals, which prevent re-colonisation of the land. Open-pit mining puts demands on local water sources, affecting habitats in lakes and rivers. Water can become contaminated with toxic metals from the mining site, damaging aquatic habitats.

Oil spillages around oil wells are extremely toxic. Once the oil seeps into the soil and water systems, habitats are destroyed (Figure 19.32)

▲ **Figure 19.32** Oil pollution in a rice field

Mining for raw materials like gold, iron, aluminium and silicon leaves huge scars in the landscape and destroys large areas of natural habitat (Figure 19.33). The extraction of sand and gravel also leaves large pits that prevent previous habitats redeveloping.

▲ **Figure 19.33** Open-pit gold mine in New Zealand

In response to this increased human activity, in 1982 the United Nations developed the World Charter for Nature. This was followed in 1990 by The World Ethic of Sustainability, created by the World Wide Fund for Nature (WWF), the International Union for Conservation of Nature (IUCN) and the United Nations Environment Programme (UNEP). Habitat conservation and the need to protect natural resources from depletion were included in this charter. In 1992, at the Earth Summit in Rio, the United Nations met again to reaffirm the contents of the World Charter for Nature. Further meetings, such as the 2009 United Nations Climate Change Conference in Denmark, have been held regularly to try to address major issues facing the natural world.

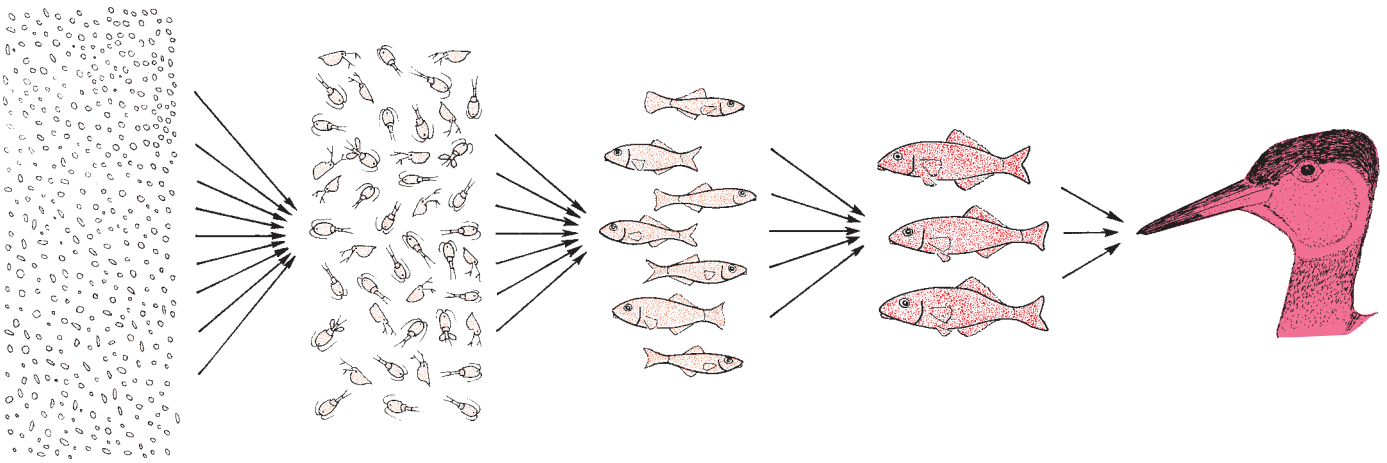
Pollution

FOCUS POINTS

- ★ How are we polluting the environment?
- ★ What is eutrophication?
- ★ What is the greenhouse effect and how is it linked to climate change?

Pollution due to pesticides

Marine habitats around the world are becoming contaminated with pesticides (insecticides and herbicides). Figure 19.34 shows how pesticides become concentrated in organisms as they move up the food chain. In larger organisms, the concentrations can be toxic.



▲ **Figure 19.34** Pesticides may become more concentrated as they move along a food chain. The intensity of colour represents the concentration of DDT

Sewage

Diseases like typhoid and cholera are caused by certain bacteria when they get into the human intestine. The faeces passed by people suffering from these diseases will contain the harmful bacteria. If the bacteria get into drinking water, they may spread the disease to hundreds of other people. For this reason, among others, untreated sewage must not be emptied into rivers. It is treated at the sewage works so that all the solids are removed. The human waste is broken down by bacteria and made harmless (free from harmful bacteria and poisonous chemicals). However, the breakdown products include phosphates and nitrates. When the water from the sewage treatment is discharged into rivers it contains large quantities of phosphate and nitrate, which allow the microscopic plant life to grow very rapidly (Figure 19.35).

▲ **Figure 19.35** Growth of algae in a lake. Large concentrations of nitrate and phosphate from treated sewage and from farmland make this growth possible

Fertilisers

When nitrates and phosphates from farmland and sewage escape into water they cause excessive growth of microscopic green plants. This may result in a serious oxygen shortage in the water, resulting in the death of aquatic animals.

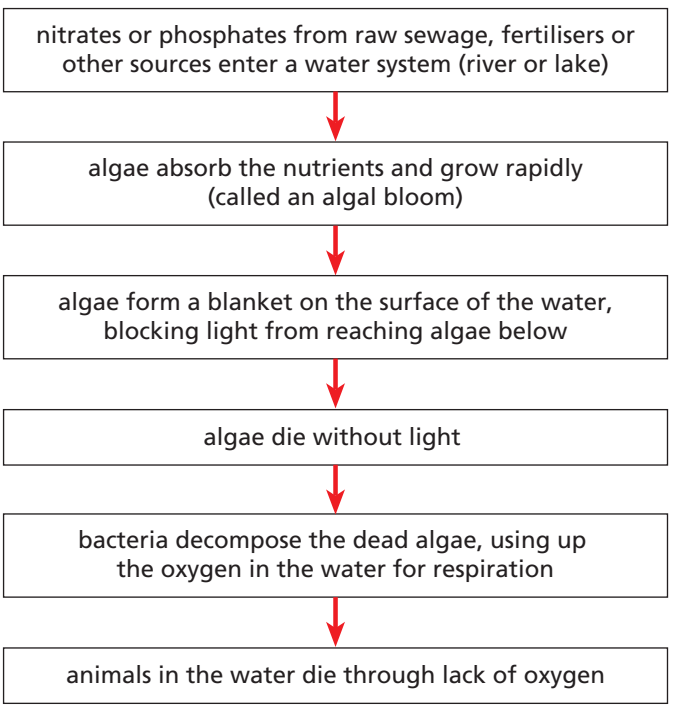
Effects of sewage and fertilisers on aquatic ecosystems

Nitrates and phosphates are present in several sources, including untreated sewage, detergents from manufacturing and washing processes, arable farming and factory farming.

If these nitrates or phosphates enter a water system, they become available for algae (aquatic plants) to absorb. The plants need these nutrients to grow. More nutrients result in faster growth (Figure 19.35). Through shortage of light because of overcrowding, more plants die. Aerobic bacteria decompose them and respire, taking oxygen out of the water. As oxygen levels drop, animals like fish cannot breathe, so they also die and the whole ecosystem is destroyed (Figure 19.36).

▲ **Figure 19.36** Fish killed by pollution. The water may look clear but it is so short of oxygen that the fish have died from suffocation

Figure 19.37 shows this sequence of events as a flow chart.



▲ **Figure 19.37** The events leading to death of an aquatic ecosystem

Eutrophication

Chapter 6 explained that plants need a supply of nitrates for making their proteins. They also need a source of other ions for many chemical reactions in their cells. The rate at which plants grow is often

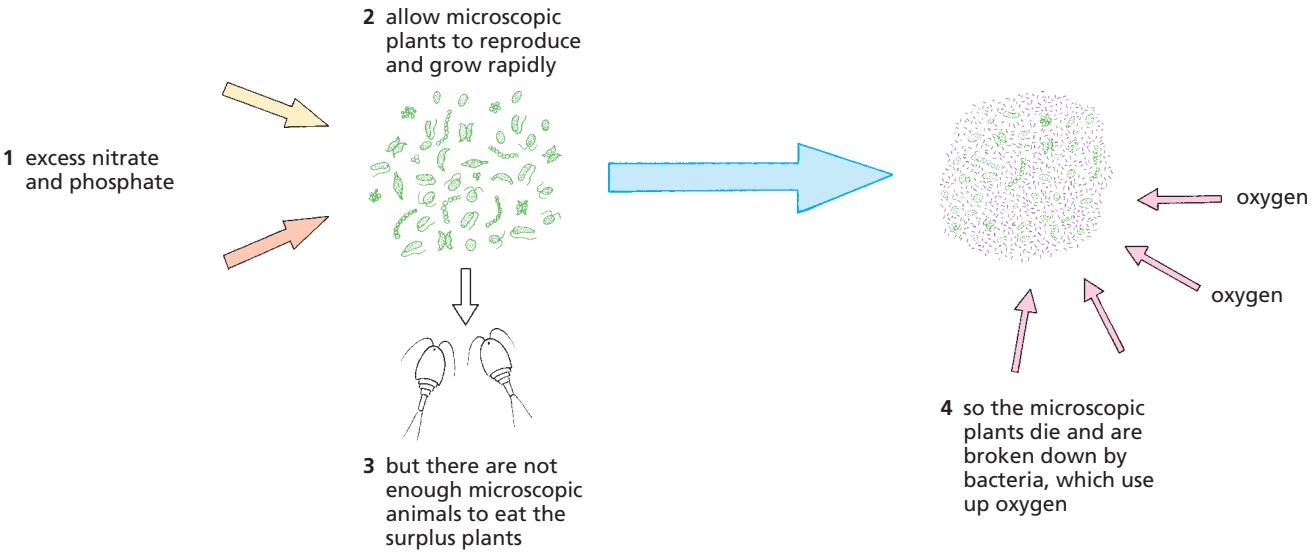
limited by how much nitrate and other ions they can obtain. In recent years, the amount of nitrate and other ions in our rivers and lakes has been greatly increased. This leads to a faster process of **eutrophication**.

Eutrophication is the enrichment of natural waters with nutrients that allow the water to support an increasing amount of plant life. This process takes place naturally in many inland waters, but usually very slowly. The large amount of enrichment that results from human activities leads to an overgrowth of microscopic algae (Figure 19.35). These aquatic algae are at the bottom of the food chain. The extra nitrates and other ions that come from sewage, farming and detergents enable them to increase very quickly. They cannot be kept in check by the microscopic animals which normally eat them. So, they die and fall to the bottom of the river or lake. Here, their bodies are broken down by bacteria. The bacteria need oxygen to carry out this breakdown and the oxygen is taken from the water (Figure 19.38). So much oxygen is taken that the water has none left (it is deoxygenated) and can no longer support animal life. Fish and other organisms die from suffocation (Figure 19.36).

The degree of pollution of river water is often measured by its biochemical oxygen demand (BOD). This is the amount of oxygen used up by a sample of water in a fixed time. The higher the BOD, the more polluted the water is likely to be.

It is possible to reduce eutrophication by using

- detergents with less phosphates
- agricultural fertilisers that do not dissolve so easily
- animal wastes on the land instead of letting them reach rivers.



▲ **Figure 19.38** Processes leading to eutrophication

Going further

Causes of eutrophication

The following processes are the main causes of eutrophication.

Use of detergents

Some detergents contain a lot of phosphate. This is not removed by sewage treatment and is discharged into rivers. The large amount of phosphates encourages growth of microscopic plants (algae).

Factory farming

Chickens and calves are often reared in large sheds instead of in open fields. Their urine and faeces are washed out of the sheds with water, forming slurry. If this slurry gets into streams and rivers it supplies an excess of nitrates and phosphates for the microscopic algae.

Discarded plastics

Towns and cities are getting bigger and bigger. They have growing populations and this leads to problems of waste disposal. The domestic waste from a town of several thousand people can cause disease and pollution if there is no effective way of disposing of it. Much waste ends up in landfill sites. These take up valuable space, pollute the ground and attract vermin and insects, which can spread disease. Many items we buy come in plastic packaging. If this is not recycled it ends up in landfill sites or is burned, causing air pollution. Discarded plastics that end up in the sea can cause severe problems for marine animals.

Plastics and the environment

Plastics are not biodegradable and are not broken down by decomposers when dumped in landfill sites or left as litter. This means that they remain in the environment (Figure 19.39), taking up valuable space or causing visual pollution. Discarded plastic bottles can trap small animals; nylon fishing lines and nets can trap birds and mammals like seals and dolphins (Figure 19.40). As the plastics in water gradually deteriorate, they fragment into tiny pieces. These are eaten by fish and birds, making them ill.

▲ **Figure 19.39** Plastics washed up on a shoreline

▲ **Figure 19.40** Seal trapped in a discarded fishing net

Plastic bags are a big problem. They take up a lot of space in landfill sites. Bangladesh was the first country to ban plastic bags in 2002. The Republic of Ireland introduced a plastic bag fee to try to control the problem. It had a dramatic effect, cutting the use of single-use bags from 1.2 billion to 230 million a year. The litter problem that plastic bags create was also reduced. Revenue raised from the fee is used to support environmental projects. Many countries, like China, Brazil, and some states in America, have now banned plastics bags, or impose a tax on them.

Polythene waste is now also recycled (Figure 19.41). The plastic is used to make items like car seat covers, sports shoes, hi-fi headphones and even roads (Figure 19.42).

▲ **Figure 19.41** Recycling polythene. Polythene waste is recycled for industrial use

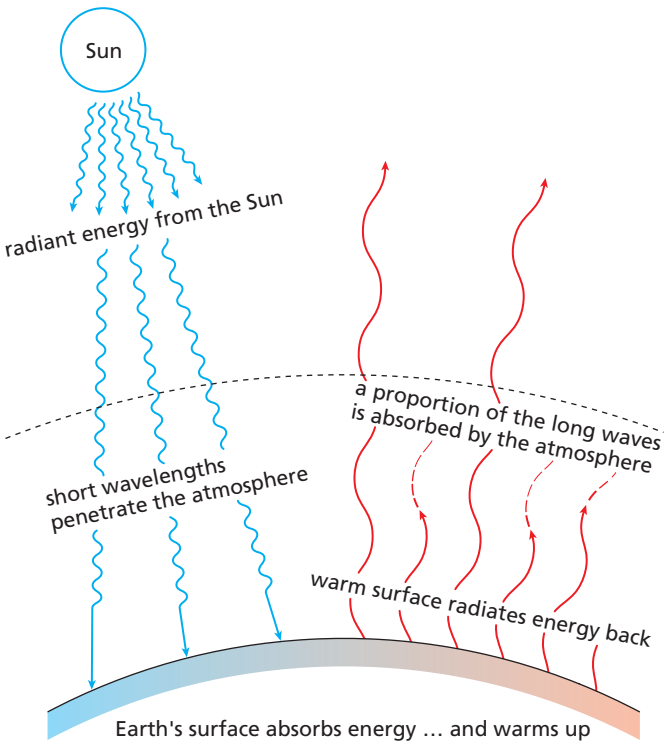
▲ **Figure 19.42** *Plasphalt* is made up of grains of plastic produced from unsorted plastic waste. This replaces the sand and gravel usually used in asphalt production for road surfaces. It can also contain recycled glass pellets

The greenhouse effect and climate change

Levels of carbon dioxide in the atmosphere are influenced by natural processes and by human activities. Processes that change the balance include

- cutting down forests (deforestation) – less photosynthesis
- combustion of fossil fuels (coal, oil and gas)
- increasing numbers of animals (including humans) – they all respire.

An increase in levels of carbon dioxide in the atmosphere is thought to contribute to global warming (Figure 19.43). Carbon dioxide forms a layer in the atmosphere, which traps heat radiation from the Sun.



▲ **Figure 19.43** The greenhouse effect

Methane also acts as a greenhouse gas. Its levels in the atmosphere have more than doubled over the past 200 years and its effects on global warming are much greater than carbon dioxide. It is produced by the decay of organic matter in anaerobic conditions, for example, in wet rice fields and in the stomachs of animals, such as cattle and termites. It is also released from the ground during the extraction of oil and coal.

The build-up of greenhouse gases causes a gradual increase in the atmospheric temperature, known as the **enhanced greenhouse effect**. This can

- melt polar ice caps, causing flooding of low-lying land
- change weather conditions in some countries, increasing flooding or reducing rainfall – changing arable (farm) land to desert; extreme weather conditions become more common
- cause the extinction of some species that cannot survive in raised temperatures.

If you look back at the carbon cycle, you will see that the natural processes of photosynthesis, respiration and decay would be expected to keep the CO_2 concentration at a steady level. However, since the Industrial Revolution, we have been burning fossil fuels obtained from coal and petroleum and releasing extra CO_2 into the atmosphere. As a result, the concentration of CO_2 has increased from 0.029 to 0.039% since 1860. It is likely to go on increasing as we burn more and more fossil fuel. According to National Oceanic and Atmospheric Administration (NOAA) data, CO_2 levels rose to 407.4 ppm in 2018. NOAA states that carbon dioxide levels today are higher than at any point in at least the past 800 000 years. In Brazil, deforestation involves large areas of rainforest being burned. This is to clear the land for grazing cattle on (Figure 19.44). This all adds to the amount of carbon dioxide in the atmosphere.

▲ **Figure 19.44** Burning rainforest to clear land for cattle to graze on

It is not possible to prove beyond all reasonable doubt that production of CO_2 and other greenhouse gases is causing a rise in the Earth's temperature, i.e. global warming. However, most scientists and

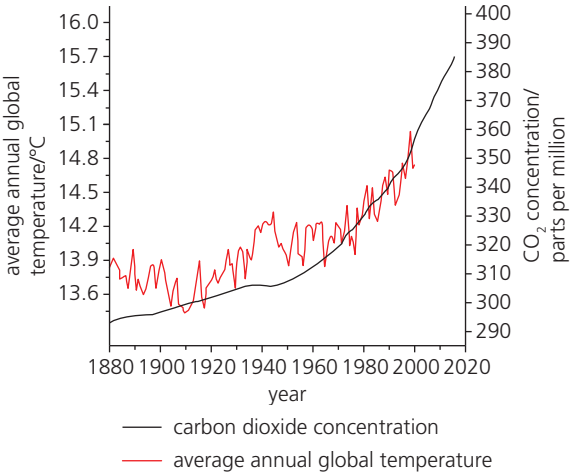
climatologists agree that it is happening now and will get worse unless we take drastic action to reduce the output of these gases.

Predictions of the effects of global warming depend on computer models. But these depend on very complex and uncertain interactions of variables.

Changes in climate might increase cloud cover and this might reduce the heat reaching the Earth from the Sun. Oceanic plankton absorb a lot of CO_2. Will the rate of absorption increase, or will a warmer ocean absorb less of the gas? In theory, an increase in CO_2 should result in increased rates of photosynthesis, bringing the system back into balance.

None of these possibilities is known for certain. The worst situation is that the climate and rainfall distribution will change and disrupt the present pattern of world agriculture; the oceans will expand and the polar icecaps will melt, causing a rise in sea level; extremes of weather may produce droughts and food shortages.

An average of temperature records from around the world suggests that, since 1880, there has been a rise of 0.7–0.9 °C, most of it very recently (Figure 19.45). However, this is too short a period from which to draw firm conclusions about long-term trends. But if the warming trend continues, it could produce a rise in sea level of between 0.2 and 1.5 metres in the next 50–100 years.



▲ **Figure 19.45** Annual average global temperatures and carbon dioxide levels since 1880

Test yourself

19 a Explain what is meant by the term *non-biodegradable plastic*.

b What are the effects of non-biodegradable plastics on

i) terrestrial ecosystems

ii) aquatic ecosystems.

20 Explain why some of the alternative and renewable energy sources are less likely to cause pollution than coal and oil.

21 Explain why carbon dioxide and methane are called greenhouse gases.

Going further

Freshwater and marine pollution

Chemical waste

Many industrial processes produce poisonous waste products. Electroplating, for example, produces waste containing copper and cyanide. If these chemicals are released into rivers, they poison the animals and plants and could poison humans who drink the water. In India, the river Ganga has become badly polluted with potentially toxic heavy metals. Growing industrial developments along the river discharge wastes into the water. Pollution has also increased through the addition of sewage and effluent from the wastewater irrigation of farmland. This process involves using water from sewage as a fertiliser.

Any factory getting rid of its effluent into water systems risks damaging the environment. Some detergents contain a lot of phosphate. This is not removed by sewage treatment and is discharged into rivers. The large amount of phosphate encourages growth of microscopic plants (algae).

▲ **Figure 19.46** River pollution

In 1971, 45 people in Minamata Bay in Japan died and 120 were seriously ill as a result of mercury poisoning. It was found that a factory had been discharging a compound of mercury into the bay as part of its waste. Although the mercury concentration in the sea was very low, its concentration was increased as it passed through the food chain (see Figure 19.34). By the time it reached the people of Minamata Bay in the fish and other sea food that formed a large part of their diet, it was concentrated enough to cause brain damage, deformity and death.

High levels of mercury have also been detected in the Baltic Sea and in the Great Lakes of North America.

▲ **Figure 19.47** The clean-up operation after an oil spill in the sea near Chennai, India

Oil pollution of the sea has become a familiar event. In 2017 two ships collided in the sea near Chennai in India (Figure 19.47). One of them had a full load of heavy oil, which leaked into the sea. Turtles and hundreds of fish were killed, and the local fishing industry was badly disrupted. When oil is spilt into water, lighter oils float on the surface, creating dangers for any organisms using the habitat (Figure 19.48).

▲ **Figure 19.48** Oil pollution. Oiled sea birds like this long-tailed duck cannot fly to reach their feeding grounds. They also poison themselves when trying to clean the oil from their feathers

Marine habitats around the world are becoming contaminated with human debris. This includes untreated sewage, agricultural fertilisers and pesticides. Plastics are a huge problem: many are non-biodegradable, so they persist in the environment (see earlier in the chapter). Others form micro-particles as they break down and are eaten by marine organisms for food, although they are indigestible. They stay in the stomach, causing sickness, or prevent the gills from working efficiently. Where fertilisers and sewage enter the marine environment, *dead zones* develop where there is not enough oxygen to maintain life. This destroys habitats.

Oil spills wash up on the intertidal zone, killing the seaweeds that provide nutrients for food chains. Filter-feeding animals like barnacles (a type of crustacean) and some species of mollusc die from taking in the oil.

Conservation

FOCUS POINTS

- ★ What is a sustainable source and how can they be managed?
- ★ Why do organisms become endangered or extinct?
- ★ How are endangered species conserved?
- ★ What are the reasons for conservation programmes?
- ★ What might happen to a species if its population size decreases?
- ★ How can we conserve our resources and prevent the extinction of organisms?

Key definitions

A **sustainable resource** is one that is produced as rapidly as it is removed from the environment so that it does not run out.

Some resources, like forests and fish stocks, can be maintained with careful management. This may involve replanting land with new seedlings as mature trees are cut down and controlling the activities of fishermen operating where fish stocks are being reduced. The ASTAF-PRO project is an example of sustainable tomato and fish production.

Going further

Tomato fish project

The ASTAF-PRO project – Aquaponic System for (nearly) Emission-Free Tomato and Fish Production – in Germany is run by the Leibniz Institute of Freshwater Ecology and Inland Fisheries. The scientists have developed a way of producing fish and tomatoes at the same time in a closed greenhouse environment. This means that the fish stocks in the ocean are not run down and the cost of maintaining them is kept low without damaging the environment. The fish and tomatoes both grow best at a temperature of 27 °C. The benefits of the system are:

- It is almost emission-free, so atmospheric CO_2 levels are not affected.
- It recycles all the water in the process and does not put any waste into the environment (Figure 19.49).
- All the energy needed to heat the greenhouses is generated by solar panels.

These factors make it a sustainable and climate-friendly method of food production. The scientists recognised that fish and plants have very similar environmental needs for their growth.

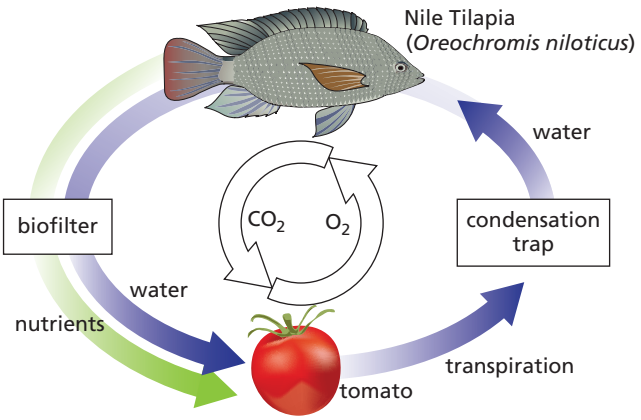
Fish

Nile Tilapia (*Oreochromis niloticus*) is chosen as the fish species. This fish survives well in artificial conditions, growing and maturing quickly. Since they are omnivorous as adults, no fish meal diet is needed, and they can be fed with pellets of processed food extracted from plants. Water from the fish tanks is cleaned and the nutrients remaining in it are used as a fertiliser for tomato plants, grown in the same greenhouse (Figure 19.50).

Tomatoes

The plants are grown on mineral wool, through which the nutrient-rich water flows. This avoids soil, which can contain pathogens. This method of growing plants is called hydroponics and means that no peat is needed for soil. The removal of peat for use in horticulture is threatening heathland and the organisms living on it.

As the tomato plants transpire, the water vapour is condensed and recycled into the fish tanks. The tomatoes are harvested and sold under the name *fish tomatoes*. The scientists call the project *The Tomatofish*. The next goal is to introduce the system into global food production systems.



▲ **Figure 19.49** The tomato fish project

▲ **Figure 19.50** Tomatoes and fish being grown in the same environment

Conservation of forests

Conservation is an active process of developing strategies to prevent the loss of Earth's biological diversity.

There are several ways of sustaining the numbers of key species of trees. These include:

1 Education

Local communities need to be educated about conservation so they understand why it is important. People are then more likely to care for the environment they live in and protect the species in it.

In tropical rainforests, it has been found that the process of cutting down the trees also damages the surrounding trees. Dragging the trees out of the forest also creates more damage. Through education, the men carrying out the tree-felling are learning alternative ways to reduce wastage and select species of trees to be

felled. This makes the process more sustainable and helps to conserve rarer species.

Organisations like the Rainforest Alliance provide education programmes for farmers in countries like Costa Rica. The programmes are designed to make the farmers aware of the importance of protecting forestry near their land, so that the rich diversity of plants and animals is maintained. The farmers benefit by being given help in increasing the productivity of their land.

2 Protected areas

Areas where rare species of trees grow need to be protected to prevent them being felled for timber or to clear the land for other purposes. Conservation areas can be set up by governments where rare endangered species are protected by tree preservation orders (TPOs). A TPO prohibits any damage being done to the protected trees. Some organisations help to conserve areas of forest. For example, the Wildlife Alliance helps to protect forests in the *Southeast Asian* tropical belt. This is important as some animal species rely on certain trees for food and shelter.

3 Legal quotas

The Rainforest Alliance has introduced a scheme called *Smartlogging*. This is a service, which gives a certificate to a logging company. This shows they are working legally and in a sustainable way to protect the environment. The timber can be tracked from where it is felled to its final export destination and its use in timber products. The customer can then be reassured that the timber in the product is from a reputable source and has not been removed illegally.

In some areas of China where bamboo is growing, there are legal quotas to prevent too much felling. Some animals like giant pandas rely on the bamboo for their food.

In Britain it is illegal to cut down trees without permission. The Forestry Commission issues licences for tree-felling.

4 Replanting

In 2017, a project was started in Brazil sponsored by Conservation International, the Brazilian Ministry of Environment and other organisations. The aim was to plant 73 million new trees, using seeds collected by volunteers. This is being done to try to recover large areas of rainforest that have been deforested for agricultural purposes.

A huge group of people worked together in India in 2016 to plant 50 million trees in just 24 hours as part of the country's effort to reforest 12% of its land by 2030.

Pakistan hit its billion tree goal in 2017. The hills of a province in the country's north-western region were planted with saplings as part of a reforestation project called the Billion Tree Tsunami. It was done to restore the province's depleted forests and fight the effects of climate change.

Similarly, China is planning to restore 69.2 million acres of forest land.

Waste paper can be pulped and used again, mainly for making paper and cardboard. Newspapers are de-inked and used again for newsprint. One tonne of waste paper is equivalent to about 17 trees. (Paper is made from wood-pulp.) So, collecting waste paper may help to cut a country's import bill for timber and spare a few more hectares of natural habitat from commercial forestry.

Conservation of fish stocks

1 Education

In the tomato fish project in Germany (see earlier), the Research Institute involved has an active education programme to inform the public about its work in sustainable development. It has even published a book for children (*Nina and the tomato fish*) to educate them about the topic.

In some parts of the world, local fishermen have over-exploited fish stocks. They have destroyed habitats by using dynamite and cyanide to kill and catch fish. These methods kill all the organisms in the area; whole coral reefs have been destroyed. Education helps the fishermen understand the effects of their methods. They know that if they protect the environment, the fish can survive, grow well, breed and provide them with a living for the future.

2 Closed seasons

A closed season is a part of the year when it is illegal to fish for some species of fish in an area of water. This allows the fish to spawn and mature so that they can breed successfully. In this way, fish stocks are maintained.

For example, in 2019, the Ministry of Fisheries in Ghana announced it was going to extend its closed season from one to two months. During this time, fishermen were not allowed to go to sea to fish. This helped fish stocks to recover, which had been reducing.

3 Protected areas

Marine protected areas are clearly defined geographical spaces. They are managed (often legally enforced) to achieve the long-term conservation of nature in that space. They are a way of preventing the capture and removal of fish so that fish stocks can rebuild and the fisheries nearby become sustainable.

4 Control of net types and mesh size

Fishing net types and mesh sizes are closely regulated in some parts of the world to ensure that fish are not caught randomly, and that undersized fish can escape capture.

Trawl nets can be very destructive (see the section on Overfishing on page 343). Coral reefs are particularly at risk to this type of fishing. Trawl nets are banned in some parts of the world to protect marine habitats and the organisms living in them.

A gillnet is a wall of netting that hangs in the water column, with floats to hold it in position. The mesh size allows fish to get their head through the netting, but not their body. The fish's gills then get caught in the mesh as the fish tries to escape from the net. Scientists have discovered that the addition of LED lights to the tops of gillnets is very effective in reducing the accidental catches of turtles and dolphins. The lights do not reduce the number of fish caught. Gillnets often have high bycatch rates of threatened marine species, so the development is a welcome one for marine conservation.

5 Legal quotas

In Europe, the Common Fisheries Policy sets quotas for fishing. The quotas help to manage fish stocks and protect species that were becoming endangered through overfishing. Quotas are set for each species of fish taken commercially and for the size of fish. This allows fish to reach breeding age and maintain or increase their populations.

Quotas are not universally popular because fishermen who catch too many fish, or species of fish not included in their quota, are not allowed to sell them. The surplus fish are thrown back but are already dead, so the fish population has been reduced anyway.

6 Monitoring

Fisheries inspectors monitor commercial fish catches. They record catches and use estimates of fish populations, so helping to conserve fish stocks. Many countries use fisheries patrol vessels (Figure 19.51) to make sure that fishing boats are licensed, not fishing in protected areas, using the correct equipment, and are keeping to their quotas.

▲ **Figure 19.51** Vietnamese patrol vessels about to seize a fishing boat suspected of fishing illegally

Test yourself

22 State what you understand by
- **a** biodiversity
- **b** sustainable resource.

23 **a** Outline what pressures lead to destruction of tropical forests.
- **b** Give three important reasons for trying to preserve tropical forests.

24 **a** Outline the measures being taken to conserve fish stocks.
- **b** Give three reasons for conservation programmes.

Endangering species and causing their extinction

Anything that reduces the population of a species endangers it (puts it at risk of extinction). Factors that endanger species include habitat destruction, the introduction of other species, hunting, international trade and pollution. Climate change can also put species at risk of extinction.

Species become extinct in the course of evolution. After all, the fossil remains of plants and animals represent organisms that became extinct hundreds of thousands of years ago. There have been periods of mass extinction, like that which wiped out the dinosaurs 65 million years ago.

The background extinction rate for a group of animals (e.g. birds) might be one species in 100–1 000 years. Today, as a result of human activity, the rate of extinction has gone up by at least ten times and possibly as much as 1 000 times. Some estimates suggest that the world is losing one species every day and within 20 years at least 25% of all forms of wildlife could become extinct. However, reliable evidence for these figures is hard to find.

A classic example is the colonisation of the Pacific islands by the Polynesians. They hunted and ate the larger bird species and introduced rats, which ate the eggs and young of ground-nesting species. Their goats and cattle destroyed plant species through grazing and trampling. Of about 1 000 plant species, 85% have been lost since they were first discovered.

This may be an extreme example, but these sorts of changes are happening all over the world. For example, the World Wide Fund for Nature estimated that only about 3 000 tigers remained in the wild in 2019. This is less than 5% of their number in 1900 (Figure 19.52). They are hunted for their skins and their bones and some body parts are used in traditional Chinese medicines.

▲ **Figure 19.52** In 110 years the tiger population has fallen from 120 000 to 3 000

Some species of animal are introduced by accident into different ecosystems. They find their way in due to man's activities and then upset food chains. One example happened in the Great Lakes in Canada and the USA. The lakes were artificially linked with shipping canals to provide transport links. However, sea lampreys found their way into the lakes through the new waterways. The lampreys had no natural predators in the lakes and fed on trout by sticking to them with their circular mouths and boring into their flesh (Figure 19.53). The fisheries in the lakes harvested about 7 million kilograms of trout annually before the lampreys entered the water systems. Afterwards, the harvest dropped to about 136 000 kilograms, so the fisheries collapsed. The lampreys are now controlled to allow the trout population to recover.

Climate change is also responsible for a reduction in the number of species. Most scientists agree that processes like global warming are made worse by human activity.

▲ **Figure 19.53** Sea lamprey feeding on a trout

Global warming is causing oceans to warm up. Even prolonged temperature increases of just one or two degrees can have a devastating effect. In 1994, coral colonies in the Indian Ocean were seen to eject food-producing algae that live inside them. As the coral rely on the algae, if they lose them, they die. The coral reefs became bleached. When the area was surveyed again in 2005, four fish species appeared to be extinct and six other species had reduced to the point of being endangered. Increases in CO_2 in the sea also affect coral reefs. The CO_2 dissolves in the water, making it more acidic. The acid dissolves the calcium carbonate deposited in the coral, making it collapse.

Species like the Atlantic cod are becoming endangered and at possible risk of extinction, partly because of overfishing but also because of climate change. Cod survive in cold water. As seawater warms up, the cod migrate north. However, the populations of microscopic plankton that cod rely on further down the food chain are also sensitive to temperature change. So, cod may not have the food supplies they need to survive.

Scientists developed a computer model to study the effect of climate change on fish stocks over the next 50 years. It predicted a large-scale redistribution of species and the extinction of some species, with the disruption of ecosystems and reduction in biodiversity.

Conservation of species

Species can be conserved by passing laws that make killing or collecting them an offence. These involve international agreements on global bans or trading restrictions (Figure 19.54), and conserving habitats.

Habitats can be conserved in several ways:

- Using laws to protect the habitat.
- Using wardens to protect the habitat.
- Reducing or controlling public access to the habitat.
- Controlling factors like water drainage and grazing, which may otherwise help to destroy the habitat.

The Indian government has set up many national parks, wildlife sanctuaries, wetlands and bio-reserves to conserve wildlife and their habitats. Other initiatives include projects to protect endangered species like tigers, elephants, crocodiles, rhinos, vultures and turtles.

CITES (Convention on International Trade in Endangered Species) gives protection to about 5 800 animals and 30 000 plants by persuading governments to restrict or ban trade in endangered species or their products, for example, snake skins or rhino horns. In 2020, 183 countries were part of the Convention.

The WWF operates on a global scale and works in over 100 countries. The WWF raises money for conservation projects in all parts of the world, especially for endangered species and habitats.

The IWC (International Whaling Commission) was set up to try and avoid the extinction of whales as a result of uncontrolled whaling and is supported by 88 member countries.

In 1982, the IWC declared a complete ban on all whaling, which is still in place in 2020.

▲ **Figure 19.54** Trying to stop the trade in endangered species. A customs official checks an illegal cargo impounded at a customs post

Education

Education plays an important role in the conservation of endangered species. Through education, populations can become more aware of the importance of endangered species of plants and animals and ways in which they can be conserved. Popular TV documentaries and news items can bring the issues to a wider audience, creating a greater awareness of the threats posed to species and the need for their conservation.

Captive breeding and reintroductions

If a species has not become totally extinct, it may be possible to boost its numbers by **breeding in captivity** and releasing the animals back into the environment. It is important that (1) the animals do not become dependent on humans for food and (2) there are suitable habitats left for them to recolonise.

In India, success has been achieved with lion-tailed macaque monkeys (Figure 19.55). It is no longer on the list of the 25 most endangered species of primates in the world.

▲ **Figure 19.55** Lion-tailed macaques are being bred in an Indian zoo

Critically endangered white-rumped vultures have been released in Nepal after a captive breeding programme (Figure 19.56). Their populations have reduced to dangerously low levels as a result of the birds feeding on the remains of dead animals that had been treated with a veterinary drug.

Sea eagles, red kites and ospreys have been introduced from areas where they are plentiful to areas where they had died out.

▲ **Figure 19.56** The white-rumped vulture has been bred successfully in captivity in Nepal and released into the wild

Seed banks

These are a way of protecting plant species from extinction. They include seed from food crops and rare species. They act as gene banks (see the next section). The Millennium Seed Bank Partnership was set up by Kew Botanical Gardens in London. It is a global project involving 95 partner countries. The target of the partnership is to have seeds of 25% of the world's plant species in storage by 2020, although this target may be delayed because of the coronavirus pandemic. That involves about 75 000 plant species.

Conservation programmes

If the population of a species drops, the range of variation within the species drops, making it less able to adapt to environmental change. So, the species could be threatened with extinction. When animal populations fall, there is less chance of individuals finding each other to mate.

Conservation programmes are set up for several reasons:

Maintaining and increasing diversity

Some 25 000 plant species are threatened with extinction now. This could result in a devastating loss of hereditary material and a reduction of about 10% in the genes available for crop improvement. Gene banks have been set up to preserve a wide range of plants, but these banks are at risk of accidents, disease and human error. The only secure way of preserving the full range of genes is to keep the plants growing in their natural environments. In 'Selection', Chapter 17, it was explained that crossing a wild grass with a strain of wheat produced an improved variety. This is one example of many

successful attempts to improve yield, drought resistance and disease resistance in food plants.

Reducing extinction

Conservation programmes make every effort to prevent extinction. Once a species becomes extinct its genes are lost forever. This deprives the world of genetic resources. We humans have no right to wipe out species forever. We will also deprive ourselves of the beauty and diversity of species and potential sources of valuable products like drugs. Many of our present-day drugs are derived from plants (e.g. quinine and aspirin) and there may be many more sources to be discovered. In the future, the genes in these endangered species may be useful for genetic modification, for example to produce drugs without having to harvest the organisms.

Protecting vulnerable ecosystems

Conservation programmes are often set up to protect threatened habitats so that rare species living there are not endangered. Some species of plant need very special conditions to grow successfully, for instance, wetland habitats. Some animal species have specialised diets or other needs that depend on the plants living in those wetlands. One example of a wetland being considered for conservation is the Mekong delta in Vietnam (see Figure 19.57). Some areas are under threat through drainage and conversion to agricultural land. There are also forests associated with the wetlands, where water birds roost and nest. These forests are under threat. The government of Vietnam and other organisations like the World Wide Fund for Nature realised the potential impact of these threats to biodiversity. They decided to carry out schemes to restore the wetlands.

▲ **Figure 19.57** Sarus cranes

There are many organisations involved with habitat conservation around the world. Some are global, for example, the World Wide Fund for Nature, the Nature Conservancy, Oceana and Conservation International. Others are country-based or on a smaller scale. Most countries have national parks and nature reserves to protect rare habitats and the organisms that live in them. Many countries have regulatory bodies committed to establish, manage and maintain nature reserves, protect threatened habitats and conduct research into issues linked to conservation.

Humans are affecting ecosystems on a large scale because of the growth in the population and changing patterns of use. Scientists estimate that around 40% of the Earth's land surface area is taken over by some form of farmed land. Crops are grown for food (directly, or indirectly through their use in feeding animals), extraction of drugs (both legal and illegal) and the manufacture of fuel (see details about biofuels below). Crop growth has major impacts in ecosystems, causing the extinction of many species and reducing the gene pool.

In theory, biofuels produced from plant sources should have a minimal effect on the carbon dioxide concentration in the atmosphere and so, on global warming. The carbon dioxide released when they are burned comes from the carbon dioxide they absorbed during their photosynthesis. They are *carbon neutral*. However, the harvesting of the crop and the processes of extraction and distillation all produce carbon dioxide. The net effect on atmospheric carbon dioxide is questionable.

Also, the clearing of forests to make space for fuel crops removes a valuable carbon sink (a point where carbon dioxide is removed from the atmosphere) and the burning associated with the clearance produces a lot of carbon dioxide. In addition, the use of land for growing crops for biofuels reduces the land available for growing food and increases the price of food. Currently, the benefit of producing fuel from plant material is open to question.

With all these demands on resources from ecosystems, managing them effectively is a very complicated process. This makes conservation programmes invaluable in protecting species and their habitats.

Risks to a species of decreasing population size

The population of a species may decrease in size because of an increase in predation, disease, shortage of food, or because of emigration. If the population is large, then there will be minimal reduction in the

genetic variation present. However, a smaller population would be affected because the genetic variation in the gene pool would be reduced. This would affect the ability of the species to cope with environmental change and put it at greater risk of extinction.

Going further

Use of AI and IVF in captive breeding programmes

Artificial insemination (AI) and **in vitro fertilisation (IVF)** are techniques used to improve fertility rates in captive breeding programmes.

Artificial insemination (AI)

Sometimes animals are reluctant to mate in captivity. Artificial insemination involves collecting sperm samples from the male animal then artificially introducing them into a female's reproductive system to fertilise her eggs. The sperm can be used immediately, or be frozen and stored. Being able to store the samples also means that the sperm can be sent to other centres where captive breeding programmes are being run. Being able to transport frozen sperm between geographically isolated populations can also greatly increase the genetic diversity of species. The technique has been successfully used in captive breeding programmes in Saudi Arabia, for example, to increase populations of a North African bird called the Houbara bustard, which might become extinct.

In vitro fertilisation (IVF)

'*In vitro*' means literally 'in glass'. The fertilisation is allowed to take place in laboratory glassware (hence the term 'test-tube babies'). In humans, this technique may be used where it is not possible to repair blocked oviducts. It is used in captive breeding programmes, especially with endangered monkeys, apes and other large mammals.

Sometimes females will not breed naturally, but are still able to produce viable eggs. Similarly, males may not produce adequate amounts of viable sperm.

The *female* may be given fertility drugs, which cause her ovaries to release several mature eggs at the same time. These eggs are then collected by laparoscopy, i.e. they are sucked up in a fine tube inserted through the abdominal wall. The eggs are then mixed with the male's seminal fluid and watched under the microscope to see if cell division takes place. (Figure 16.62 is a photograph of an *in vitro* fertilised egg cell.)

One or more of the dividing zygotes are then introduced to the female's uterus by means of a tube inserted through the cervix. The technique has been used to breed white rhinos and tigers. The eggs can be frozen and stored and it is possible to transfer early embryos into other females that may be infertile.

Test yourself

25 Explain how the loss of a plant species might affect
- **a** our health (indirectly)
- **b** the prospect of developing new varieties of crop plants resistant to drought.

26 a Using a suitable example, define the term *sustainable resource*.

b i) Give three reasons why some organisms are becoming endangered or extinct.

ii) Outline how a **named** endangered species can be conserved.

Revision checklist

After studying Chapter 19 you should know and understand the following:

Energy flow

- ✔ The Sun is the principal source of energy input to biological systems.
- ✔ Energy from the Sun flows through living organisms.
- ✔ First, light energy is converted into chemical energy in photosynthetic organisms. Then they are eaten by herbivores. Carnivores then eat herbivores.
- ✔ As organisms die, the energy is transferred to the environment.

Food chains and food webs

- ✔ A food chain shows the transfer of energy from one organism to the next, beginning with a producer.
- ✔ A food web is a network of interconnected food chains.
- ✔ Producers are organisms that make their own organic nutrients, usually using energy from sunlight, through photosynthesis.
- ✔ Consumers are organisms that get their energy from feeding on other organisms.
- ✔ A herbivore is an animal that gets its energy by eating plants.
- ✔ A carnivore is an animal that gets its energy by eating other animals.
- ✔ A decomposer is an organism that gets its energy from dead or waste organic material.
- ✔ A trophic level is the position of an organism in a food chain, food web, pyramid of numbers or ecological pyramid.
- ✔ Plants are the producers in a food chain or web; animals may be primary, secondary or tertiary consumers.
- ✔ Overharvesting unbalances food chains and webs, as does the introduction of foreign species to a habitat.
- ✔ Energy is transferred between trophic levels through feeding.
- ✔ Only about 1% of the Sun's energy that reaches the Earth's surface is trapped by plants during photosynthesis.
- ✔ At each step in a food chain, only a small proportion of the food is used for growth. The rest is used for energy to keep the organism alive.
- ✔ Pyramids of energy have advantages over pyramids of number or biomass to represent a food chain.
- ✔ The transfer of energy from one trophic level to another is inefficient.
- ✔ Food chains usually have fewer than five trophic levels.
- ✔ Feeding crop plants to animals uses up a lot of energy and makes the process inefficient.
- ✔ There is an increased efficiency in supplying green plants as human food.

Nutrient cycles

- ✔ The materials that make up living organisms are constantly recycled.
- ✔ Plants take up carbon dioxide during photosynthesis; all living organisms give out carbon dioxide during respiration; the burning of carbon-containing fuels produces carbon dioxide.
- ✔ The uptake of carbon dioxide by plants balances the production of carbon dioxide from respiration and combustion.
- ✔ The combustion of fossil fuels and the cutting down of forests increases the carbon dioxide concentrations in the atmosphere.
- ✔ Soil nitrates are derived naturally from the excretory products of animals and the dead remains of living organisms.
- ✔ Nitrifying bacteria turn these products into nitrates, which are taken up by plants.
- ✔ Nitrogen-fixing bacteria can make nitrogenous compounds from gaseous nitrogen.
- ✔ Plants make amino acids and proteins.
- ✔ Animals eat the proteins.
- ✔ Proteins are broken down to remove the nitrogen by the process of deamination.
- ✔ Microorganisms play an important part in the nitrogen cycle. They are involved in decomposition, nitrification, nitrogen fixation and denitrification.

Populations

- ✔ A population is a group of organisms of one species, living and interacting in the same area at the same time.
- ✔ A community is all of the populations of different species in an ecosystem.
- ✔ An ecosystem is a unit containing the community of organisms and their environment, interacting together.
- ✔ The factors affecting the rate of population growth for a population of an organism include food supply, competition, predation and disease.

Habitat destruction

- ✔ By altering food webs and food chains, humans can affect habitats.
- ✔ Deforestation is an example of habitat destruction: it can lead to extinction, soil erosion, flooding and carbon dioxide build-up in the atmosphere.
- ✔ The conversion of tropical forest to agricultural land usually results in failure because forest soils are poor in nutrients.

Pollution

- ✔ Untreated sewage, pesticides and fertilisers can pollute aquatic ecosystems.
- ✔ The process of eutrophication of water involves
  - increased availability of nitrate and other ions
  - increased growth of producers
  - increased decomposition after death of the producers
  - increased aerobic respiration by bacteria, resulting in a reduction in dissolved oxygen
  - the death of organisms requiring dissolved oxygen in water.
- ✔ Non-biodegradable plastics can have detrimental effects on aquatic and terrestrial ecosystems.
- ✔ Methane and carbon dioxide are building up in the atmosphere, resulting in the enhanced greenhouse effect and climate change.

Conservation

- ✔ A sustainable resource is one that can be removed from the environment without it running out.
- ✔ Forests can be conserved using education, protected areas, quotas and replanting.
- ✔ Fish stocks can be conserved using education, closed seasons, protected areas, controlled net types and mesh size, and quotas and monitoring.
- ✔ Some organisms are becoming endangered or extinct due to factors such as climate change, habitat destruction, hunting, pollution and introduced species.
- ✔ Endangered species can be conserved by strategies that include monitoring and protecting species and habitats, education, captive breeding programmes and seed banks.
- ✔ Reasons for conservation programmes include maintaining or increasing biodiversity, reducing extinction and protecting vulnerable ecosystems.
- ✔ There are risks to a species if its population size decreases, which include reducing genetic variation.

Exam-style questions

1 a Define the term *trophic level*. [2]

b Explain why food chains very rarely have more than five trophic levels. [2]

c In the food web in Figure 19.7, the longest food chain consists of five trophic levels.

i) Write out this food chain. [2]

ii) Suggest an organism that could represent a sixth level in the food chain. [2]

iii) Draw a pyramid of numbers for this food chain. [2]

2 a Define the term *food chain*. [2]

b i) Give an example of a food chain, with at least four organisms, from a named habitat. [2]

ii) Identify the trophic levels under the food chain. [4]

iii) Draw a pyramid of numbers based on the organisms in your food chain. Identify the organism at each level. [3]

3 Figure 19.7 shows a food web.

a i) Define the term *herbivore*. [2]

ii) Identify the herbivores in the food web. [3]

iii) Explain why it is difficult to name the trophic level at which the eagle feeds. [3]

b Suggest the effect on organisms in the food web if

i) the rats became infected with a disease and died [3]

ii) the eagles were hunted to extinction. [3]

4 a Name the process(es) in the carbon cycle which

i) take in carbon dioxide from the atmosphere [1]

ii) release carbon dioxide into the atmosphere. [1]

b Describe how carbon, removed from the atmosphere, is trapped and effectively removed from the carbon cycle. [3]

5 Describe how gaseous nitrogen can become part of a protein molecule in the muscle of a mouse. [9]

6 Describe how microorganisms are important in

a the carbon cycle [3]

b the nitrogen cycle. [3]

7 **a** Outline the advantages and disadvantages of using pesticides. [6]

b Systemic pesticides in solution are sprayed directly onto the leaves of plants. The pesticide is absorbed into the leaves. Insects that feed on the stems, shoots or leaves of the plants which have grown after spraying are killed. Use your knowledge of plant transport systems to suggest how the insects are killed. [5]

8 **a** Describe what disadvantages local farmers might experience if a forest on hills above their land was chopped down. [4]

b Suggest what effect this deforestation might have on plants and animals living in the habitat. [4]

9 A pesticide factory has chemical waste containing traces of DDT. It pours it into the sea. Local people who eat the large fish have started to show signs of DDT poisoning. The table shows levels of DDT in the water and organisms associated with the ecosystem.

source of DDT	concentration of DDT/ parts per billion
unpolluted seawater	1.0×10^{-1}
seawater containing the chemical waste	2.0
sample of plankton (microscopic animals), which take in DDT but cannot excrete it	8.0×10^{1}
small fish which feed on plankton	2.0×10^{2}
large fish which feed on small fish	1.0×10^{4}

a Draw a food chain to show how local people are becoming poisoned with DDT. [3]

b A scientist wanted to draw a bar chart to show the levels of DDT in each organism. What information is missing in the table? [2]

c Calculate the percentage increase in DDT levels between the plankton and the large fish. [2]

d The factory was also making non-biodegradable plastics.

i) Define the term *non-biodegradable*. [2]

ii) State three ways in which the plastics could pollute the environment. [3]

10 Explain why paper can be described as a sustainable resource. [3]

11 Draw a flow chart to show the process of eutrophication in a lake. [8]

Theory past paper and exam-style questions

1 Cells

1 **a** With reference to **named** components, describe how the structure of one animal cell (for example from fresh liver) would appear different from a plant cell (for example from an onion epidermis). [4]

b State the relationship between structure and function for **both** of the following:
xylem vessels
red blood cells. [6]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 8, May/June 2017

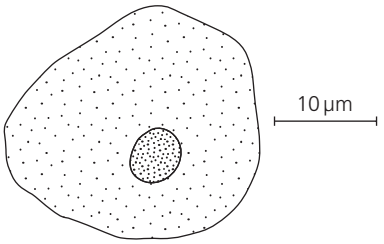
2 **a** Describe the functions of the cell membrane. [5]

b Explain the advantages to a plant of having its cell membranes surrounded by cell walls. [5]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 8, May/June 2011

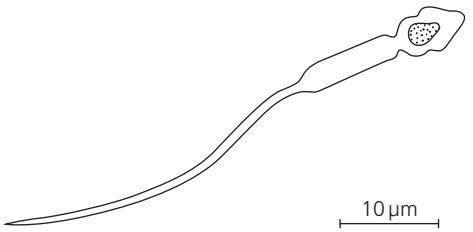
3 Figure 1.3 shows a cheek cell from the lining of a person's mouth.



▲ **Figure 1.3**

a Name the chemical found in the nucleus that controls the production of protein. [1]

Figure 1.4 shows a gamete from the same person.



▲ **Figure 1.4**

b Describe how and explain why the two cells differ in appearance. [4]

c **i)** State two ways in which the nucleus of the gamete differs from the nucleus of the cheek cell. [2]

ii) Explain why it is important that the two nuclei are different. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 2, Question 2, May/June 2008

4 Describe the similarities and differences in structure and function of root hairs and villi.

a similarities [4]

b differences [6]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 7, October/November 2014

5 With reference to a human being, explain

a what is meant by a *cell* [3]

b how tissues and organs work together in the circulatory system. [7]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 8, October/November 2010

6 Describe the functions in a plant of

a cell walls, [5]

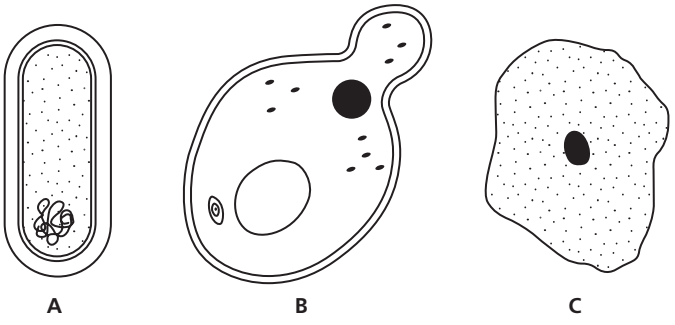
b cell membranes. [5]

[Total: 10]

Cambridge O Level Biology 5090, Paper 2, Question 8, October/November 2008

2 Classification

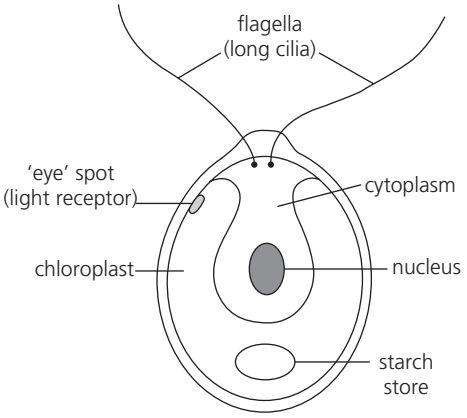
1 Figure 2.1 shows cells from three different types of organism (not drawn to the same scale).



▲ **Figure 2.1**

a Name the type of organism represented by each of the cells and in each case give a reason for your answer. [3]

b Figure 2.2 shows a one-celled organism that has both plant and animal characteristics.



▲ **Figure 2.2**

State two reasons in each case why the organism might be identified as

i) an animal [2]

ii) a plant. [2]

[Total: 7]

Cambridge O Level Biology 5090, Paper 21, Question 1, October/November 2011

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

2 Describe and compare the following:

a insects and crustaceans [5]

b viruses and bacteria. [5]

[Total: 10]

3 Movement into and out of cells

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

1 **a** Define the term *diffusion*. [2]

b Describe examples of diffusion in the following parts of the human body. In each description, state one material diffusing, where it is diffusing from and where it is diffusing to.

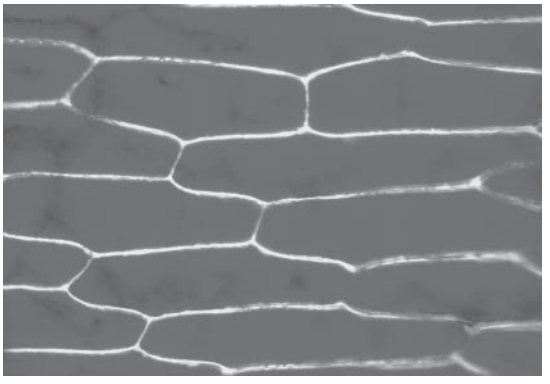
i) lungs [3]

ii) small intestine [3]

iii) kidney. [3]

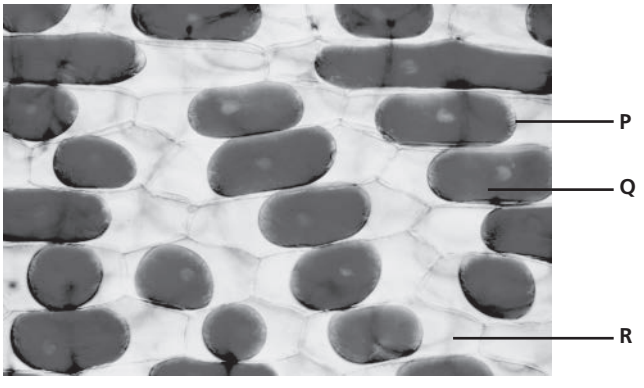
[Total: 11]

2 Figure 3.1 shows cells from a plant tissue which have been mounted on a slide with distilled water and viewed using a microscope.



▲ **Figure 3.1**

Figure 3.2 shows cells taken from the same plant tissue when mounted on a slide with concentrated salt solution.



▲ **Figure 3.2**

a Explain the appearance of the cells in Figure 3.2. [4]

b **i)** Identify structures **P** and **Q** in Figure 3.2. [2]

ii) State the contents of location **R** in Figure 3.2. [1]

iii) The concentrations of substances in structure **Q** are different from those in location **R**.
Explain how the properties of structure **P** result in differences in concentrations of substances in **Q** and **R**. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 5, October/November 2018

3 **a** Explain the importance of active transport in plants and in humans. [4]

b

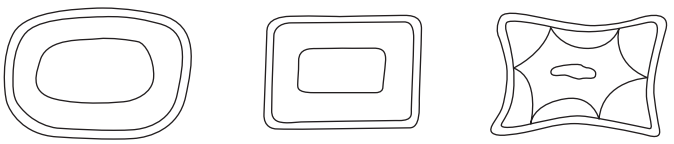
i) Explain what is meant by the term *diffusion*. [2]

ii) Explain why respiration depends on the process of diffusion. [4]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 7, October/November 2013

4 Figure 3.3 shows three similar plant cells 5 minutes after being placed in different solutions, **G**, **H** and **I**. One of these solutions has a composition and water potential exactly the same as that of the cell sap in the cells.



cell in solution **G** | cell in solution **H** | cell in solution **I**

▲ **Figure 3.3**

a On a copy of **one** of the cells in Figure 3.3, label clearly

i) with the letter **J**, a structure made of cellulose,

ii) with the letter **K**, the part of the cell that would contain the nucleus. [2]

b **i)** Identify the solution that has a **higher** water potential than the cell sap. [1]
Explain what has happened to cause the appearance of the cell in that solution. [4]

c **i)** On a copy of the cell in solution **I**, shade all the regions that would contain solution **I**. [1]

ii) Explain your answer to **(i)**. [3]

[Total: 11]

Cambridge O Level Biology 5090, Paper 2, Question 2, October/November 2009

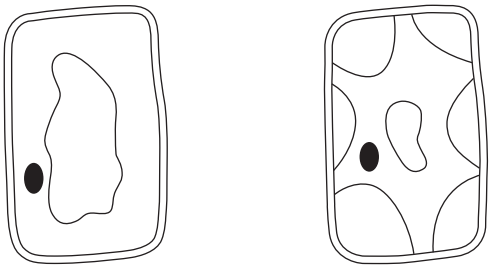
5 **a** Define osmosis and explain why osmosis is a special form of diffusion. [7]

b Explain the importance of active transport in the human alimentary canal. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 6, May/June 2019

6 Figure 3.4 shows a plant cell before and after being placed in a concentrated salt solution.



before | after

▲ **Figure 3.4**

a With reference to **named** parts of the cell, describe changes in the appearance of the cell after being placed in the concentrated salt solution. [3]

b Explain how the changes you have described in **(a)** have occurred. [3]

[Total: 6]

Cambridge O Level Biology 5090, Paper 21, Question 1, October/November 2015

4 Biological molecules

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

1 Using labels to identify the sub-units, draw diagrams to show the structures of

a lipid [2]

b carbohydrate polymer e.g. starch [2]

c protein. [2]

[Total: 6]

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

2 Which molecule contains nitrogen?
- **A** fat
- **B** glucose
- **C** lipase
- **D** starch

[Total: 1]

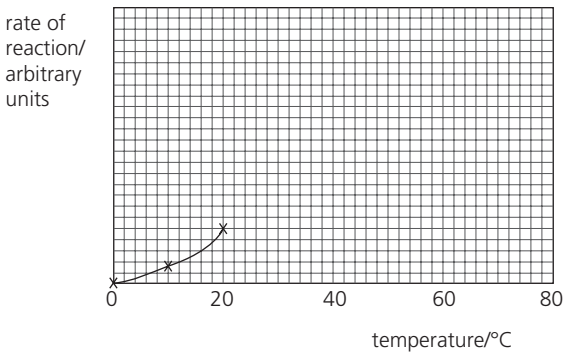
5 Enzymes

1 In living organisms, enzymes may be used in reactions to convert large molecules into smaller ones.

a State the term used for all
- **i)** molecules on which enzymes act,
- **ii)** molecules that are formed in a reaction. [2]

b For a chemical reaction that begins in the stomach, state
- **i)** the original large molecule,
- **ii)** the stomach enzyme involved,
- **iii)** the smaller molecules formed. [3]

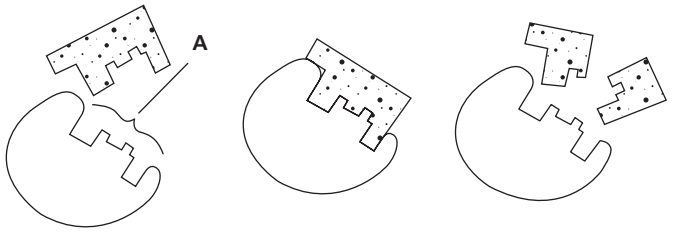
Figure 5.1 is part of a graph showing how the rate of an enzyme-controlled reaction changes with increasing temperature.



▲ **Figure 5.1**

c Copy and complete the graph in Figure 5.1 to show how the rate of this enzyme-controlled reaction changes as the temperature is increased from 20 °C to 80 °C. [3]

d Figure 5.2 shows diagrammatically how an enzyme-controlled reaction may occur.



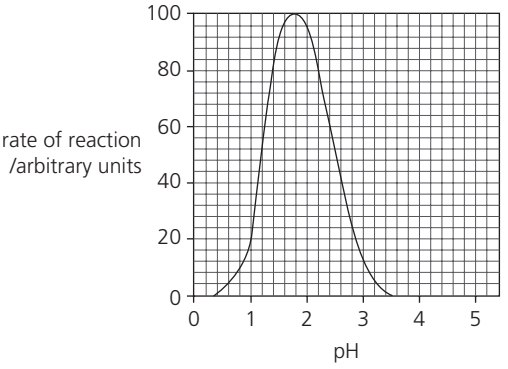
▲ **Figure 5.2**

- **i)** Identify region **A** on Figure 5.2. [1]
- **ii)** State the hypothesis illustrated in Figure 5.2. [1]

[Total: 10]

Cambridge O Level Biology 5090, Paper 2, Question 2, October/November 2007

2 Enzyme **Q** is active in the human alimentary canal. Figure 5.3 shows the effect of pH on the rate of reaction of enzyme **Q**.



▲ **Figure 5.3**

a **i)** Use the information in Figure 5.3 to name the region of the alimentary canal where enzyme **Q** is active. [1]

ii) Use your knowledge of the 'lock and key' hypothesis of enzyme action to explain why enzyme **Q** is active only in this region of the alimentary canal and not in any other region. [6]

b All enzymes contain carbon. List **three** other chemical elements that must be present in each molecule of an enzyme. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 6, May/June 2016

3 **a** Describe and explain how each of the following affects enzyme activity:
pH,
temperature. [7]

b Name **one** enzyme that acts in a **named** part of the alimentary canal and describe the role of this enzyme in digestion. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 8, October/November 2018

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

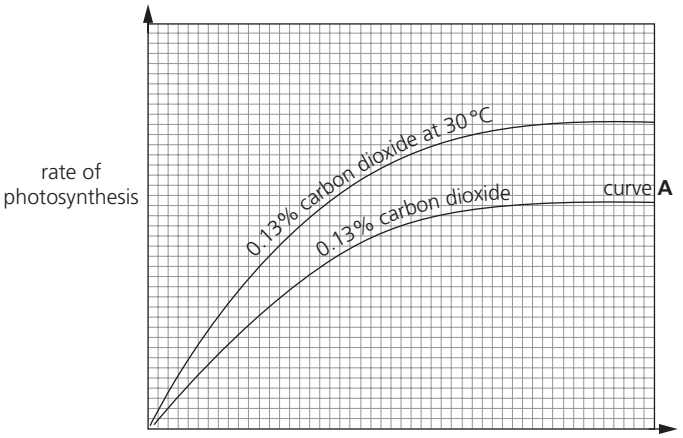
4 **a** Define the following terms:
- **i)** catalyst, [2]
- **ii)** enzyme. [2]

b State two differences between a catalyst and an enzyme. [2]

[Total: 6]

6 Plant nutrition

1 Figure 6.1 shows a graph drawn by a student of the rate of photosynthesis in a plant exposed to the same concentration of carbon dioxide at two different temperatures.



▲ **Figure 6.1**

a **i)** Name **one** limiting factor, other than carbon dioxide and temperature, that affects the rate of photosynthesis. [1]

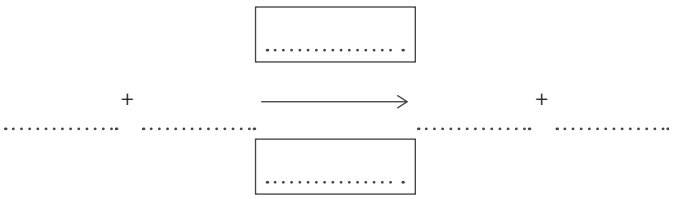
ii) Suggest a likely temperature for curve **A**. Give an explanation for your answer. [3]

b The student failed to label the horizontal (*x*) axis of the graph. Suggest a suitable label for this axis and explain your suggestion. [4]

[Total: 8]

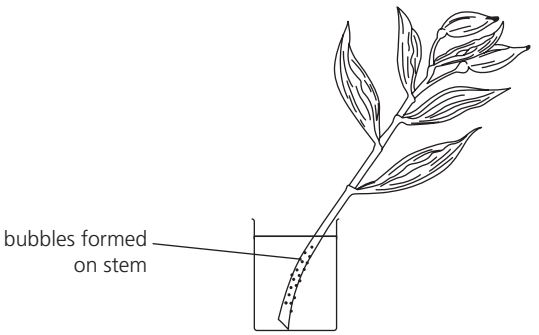
Cambridge O Level Biology 5090, Paper 21, Question 5, October/November 2013

2 **a** Copy and complete the equation to summarise the process of photosynthesis.



[2]

A young, green, leafy stem was placed in a clear glass beaker of water in bright light. Figure 6.2 shows the stem 12 hours later.



▲ **Figure 6.2**

b **i)** Suggest two places where the bubbles could have come from. [2]

ii) Tests proved that the bubbles contained oxygen. Explain how they appeared on the side of this green stem. [3]

c Explain the benefits to other organisms of having submerged water plants in a pond ecosystem. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 4, October/November 2012

3 With reference to photosynthesis,

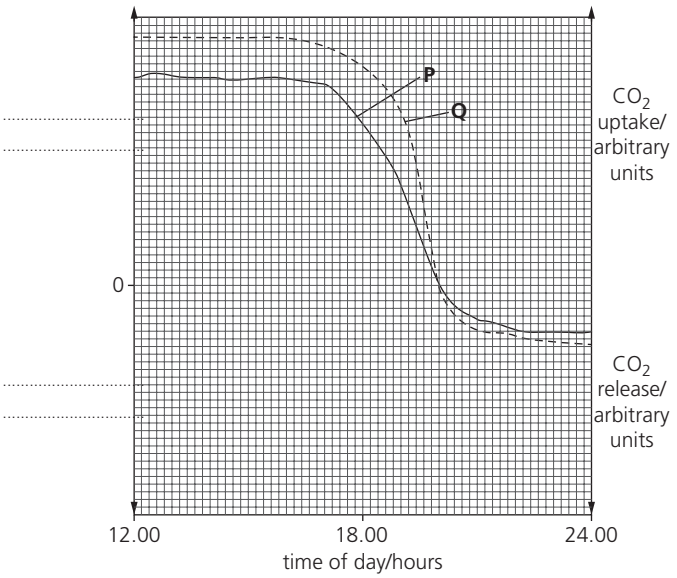
a Explain what is meant by the term *limiting factors*. [5]

b Describe the ways in which a plant obtains its oxygen for respiration. [5]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 8, October/November 2010

4 In Figure 6.3, curve **P** shows carbon dioxide uptake and release by a plant during a twelve-hour period between 12.00 hours and 24.00 hours.



▲ **Figure 6.3**

a Name the process mainly responsible for the shape of graph **P** from 12.00 hours to 16.00 hours. [1]

b i) State the time at which there is no net movement of carbon dioxide into or out of the plant. [1]

ii) Explain the shape of the curve after this time. [3]

c Name a factor that might cause the curve to appear like curve **Q** rather than curve **P** in Figure 6.3. [1]

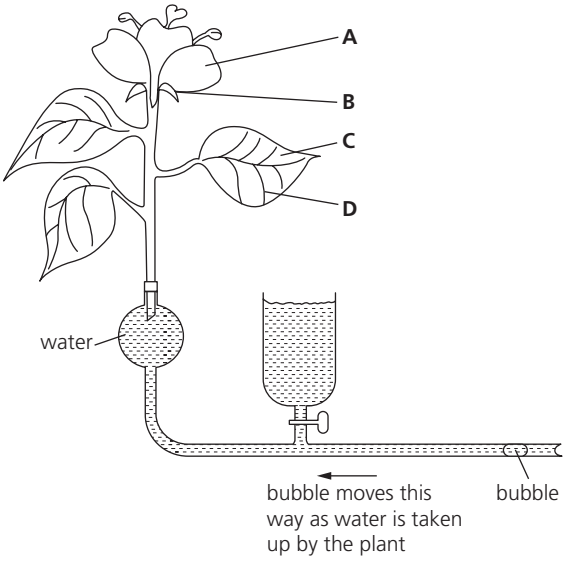
d On a copy of Figure 6.3, draw a curve to show the uptake and release of oxygen by the plant during the same period of time.
Label your axis in the spaces provided on your copy of Figure 6.3. [4]

[Total: 10]

Cambridge O Level Biology 5090, Paper 2, Question 5, October/November 2009

7 Transport in flowering plants

1 A potometer is used to measure water uptake by a plant. Figure 7.1 shows the stem and flower of a plant in a potometer. As water is taken up, the bubble moves in the direction shown.



▲ **Figure 7.1**

a Name the parts **A**, **B**, **C** and **D** in Figure 7.1. [4]

b Describe the pathway taken by water as it moves from the potometer, through the plant stem and into the surrounding air. [3]

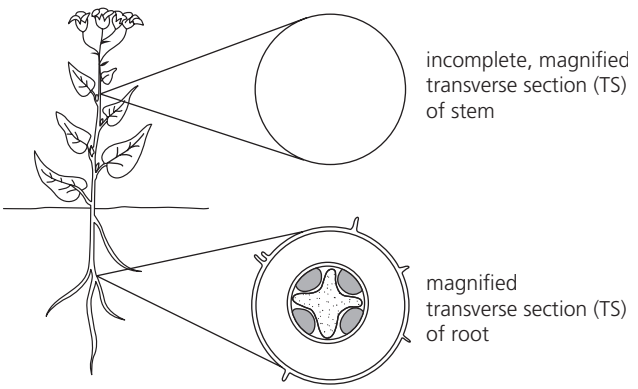
c i) In an experiment, the bubble moved a distance of 60 mm in 10 minutes. Calculate the average rate at which the bubble moved in mm per min. [1]

ii) The experiment was repeated in an area of lower light intensity.
Predict and explain what would happen to the rate at which the bubble moved. [3]

[Total: 11]

Cambridge O Level Biology 5090, Paper 21, Question 2, May/June 2017

2 Figure 7.2 shows a plant with a magnified transverse section (TS) of the root and an incomplete, magnified transverse section (TS) of the stem.



▲ **Figure 7.2**

a The transverse section of the root in Figure 7.2 shows the distribution of xylem and phloem tissue.
   i) Using a labelling line and the letter **X**, show, on a copy of Figure 7.2, the location of the xylem tissue in the transverse section (TS) of the root. [1]
   ii) Complete the transverse section (TS) of the stem on your copy of Figure 7.2 to show the distribution of xylem and phloem tissue. [2]
   iii) Using a label line and the letter **P**, show the location of the phloem tissue that you have drawn. [1]

b State the functions of phloem tissue. [3]

[Total: 7]

Cambridge O Level Biology 5090, Paper 21, Question 1, May/June 2016

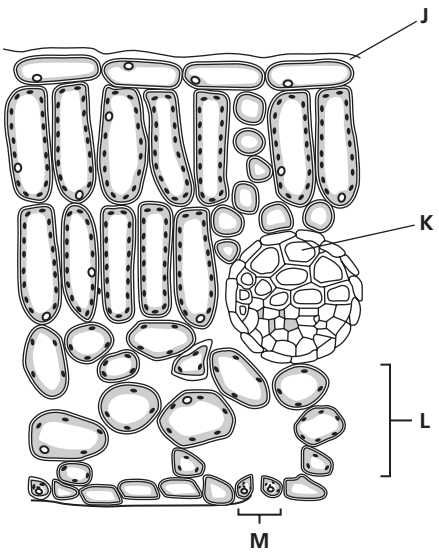
3 a Describe and explain how an **increase** in each of the following factors surrounding a plant affects the rate of transpiration:
- temperature
- light intensity
- humidity. [7]

b Suggest the importance of transpiration to a plant. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 9, May/June 2015

4 The diagram shows a magnified transverse section through a leaf.



▲ **Figure 7.3**

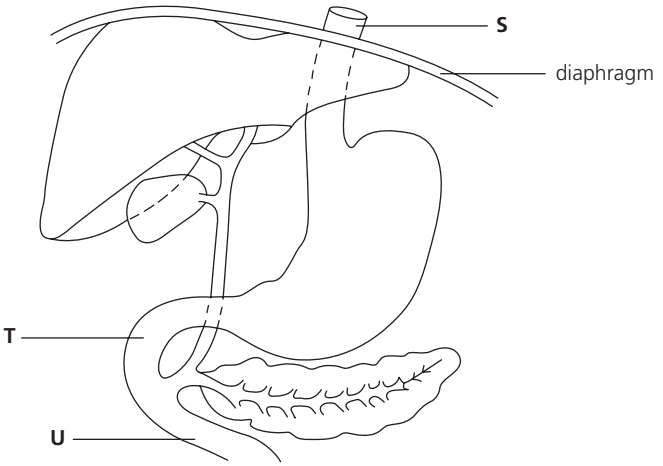
Name each of **J**, **K**, **L** and **M** and explain the importance of each in the process of transpiration. [10]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 6, May/June 2018

8 Human nutrition

1 The diagram shows a region of the alimentary canal and the associated organs.



▲ **Figure 8.1**

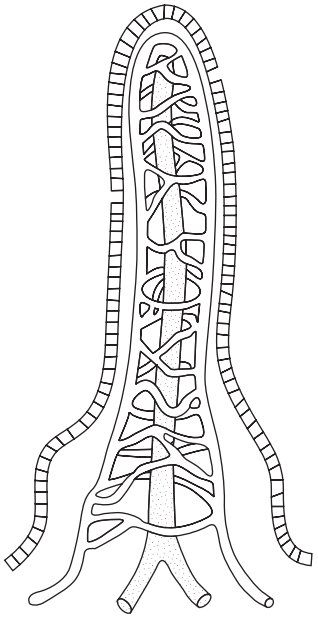
a i) Identify part **S**. [1]
   ii) Name and describe the process which moves food through part **S**. [4]

b i) Draw a ring around the correct words to complete the sentence below.
higher than **the same as** **lower than**
The pH at location **U** is .... that at location **T**. [1]
   ii) Explain how the pH at location **U** results from secretions produced by organs shown in the diagram. Name these organs. [4]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 7, October/November 2018

2 Figure 8.2 shows a structure found in part of the alimentary canal.



▲ **Figure 8.2**

a Name the structure shown in Figure 8.2 and state the part of the alimentary canal in which it is found. [2]

b Explain the ways in which this structure is adapted to enable it to carry out its function. [8]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 6, May/June 2015

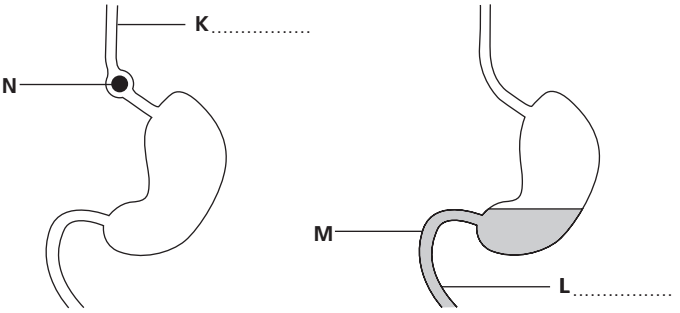
3 a Explain why most foods must be digested. [3]

b Describe the digestion of fats.
You should include reference to the following in your answer:
- named regions of the alimentary canal and associated organs
- named chemicals, including the end products of fat digestion. [7]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 6, October/November 2015

4 Figure 8.3 shows some food just before it enters the stomach and the same food as it leaves the stomach four hours later.



▲ **Figure 8.3**

a On a copy of Figure 8.3, label the structures **K** and **L**. [2]

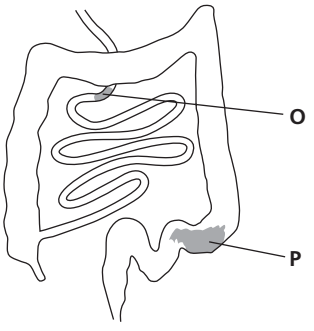
b The food consisted solely of meat and potatoes. By placing ticks ✓ in the appropriate boxes in a copy of Table 8.1, show how the major components of the food compare at positions **M** and **N**.

▼ **Table 8.1**

	more at M than at N	less at M than at N	almost the same at M and N
starch			
protein			
fibre			

[3]

Figure 8.4 shows the same food at **O**, and 24 hours later, at **P**.



▲ **Figure 8.4**

c i) Explain what has happened to the protein between **O** and **P**. [2]

ii) Name the region of the alimentary canal which will contain fibre in the highest proportion and give reasons for your answer. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 2, Question 5, May/June 2007

9 Human gas exchange

1 a Outline the sequence of events that take place in the body when a person breathes out. [5]

b State and explain the **similarities** and **differences** between air breathed in and air breathed out. [5]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 9, May/June 2012

2 Atmospheric air contains oxygen and carbon dioxide.

a Copy and complete Table 9.1 to show the percentage of oxygen and carbon dioxide in inhaled and exhaled air.

▼ **Table 9.1**

gas	% gas in air	
	inhaled air	exhaled air
oxygen		
carbon dioxide		

[2]

b i) Explain how oxygen is used by a muscle cell. [3]

ii) Explain what happens in a muscle cell when oxygen is in short supply. [2]

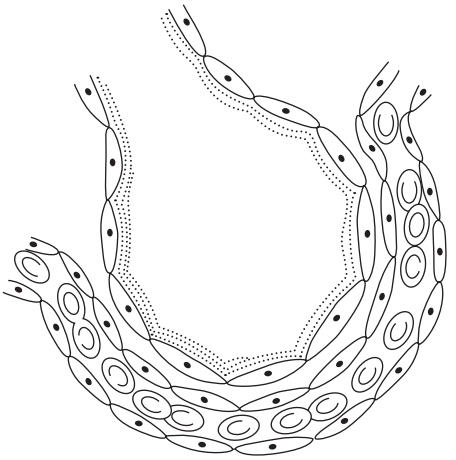
c At high altitudes, oxygen is less available than it is at low altitudes.
Suggest modifications of the circulatory and respiratory systems that might help people that live for many years at high altitude. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 3, October/November 2012

3 a Describe the role of the cilia in the trachea. [3]

b Figure 9.1 shows components of the human gas exchange surface and an associated blood vessel.



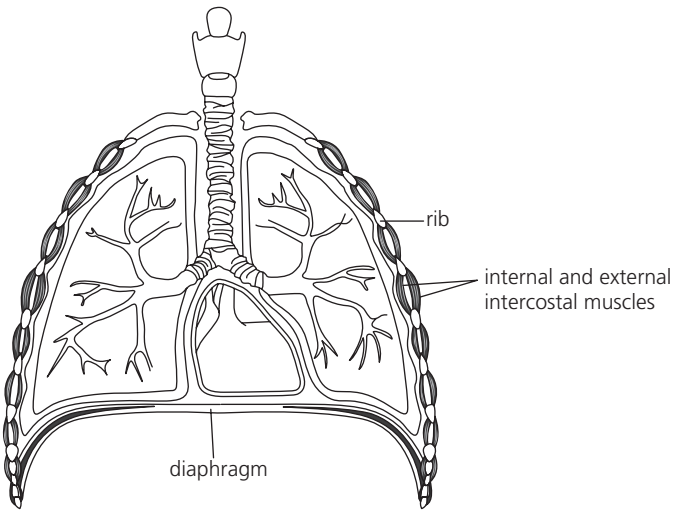
▲ **Figure 9.1**

State the characteristics, and describe the roles, of each of the components shown in Figure 9.1. You should make reference to **named** structures in your answer. [7]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 6, May/June 2017

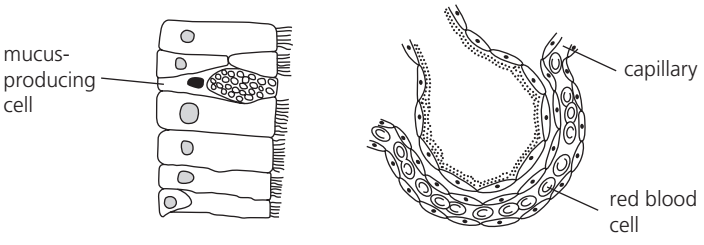
4 The diagram shows the human thorax.



▲ **Figure 9.2**

a i) Describe how each of the structures named in the diagram is involved when a person takes a single breath **in**. [3]

ii) The diagrams below show two magnified structures, **D** and **E**, from the thorax.



▲ **Figure 9.3**

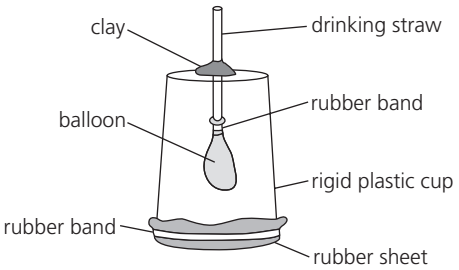
Draw lines labelled **D** and **E** on a copy of the diagram of the thorax to indicate the positions of **structure D** and **structure E**. [2]

b Describe how structure is related to function for each of the following:
a capillary,
a red blood cell. [5]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 4, October/November 2018

5 Figure 9.4 shows a model that a student made to represent the human breathing system.



▲ **Figure 9.4**

a State the part of the model shown in Figure 9.4 that represents each of the following structures:
the trachea
the diaphragm. [2]

b Describe how this model does **not** accurately represent the human breathing system. [4]

c **i)** The model can be used to demonstrate the action of breathing.
Describe what the student must do to the model to demonstrate the action of breathing in. [2]

ii) State what the student would observe as the model is used to demonstrate the action of breathing in. [1]

iii) The model becomes damaged by a hole being made in the side of the rigid plastic cup. Describe and explain how this damage will change what the student would observe as the model is used to demonstrate the action of breathing in. [3]

[Total: 12]

Cambridge O Level Biology 5090, Paper 21, Question 1, October/November 2016

10 Respiration

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

1 **a** State three uses of energy in living organisms. [3]

b **i)** State the word equation for anaerobic respiration in yeast. [2]

ii) Describe the role of yeast in bread-making. [3]

c Suggest why anaerobic respiration may be less useful than aerobic respiration. [2]

[Total: 10]

2 **a** Define *respiration*. [3]

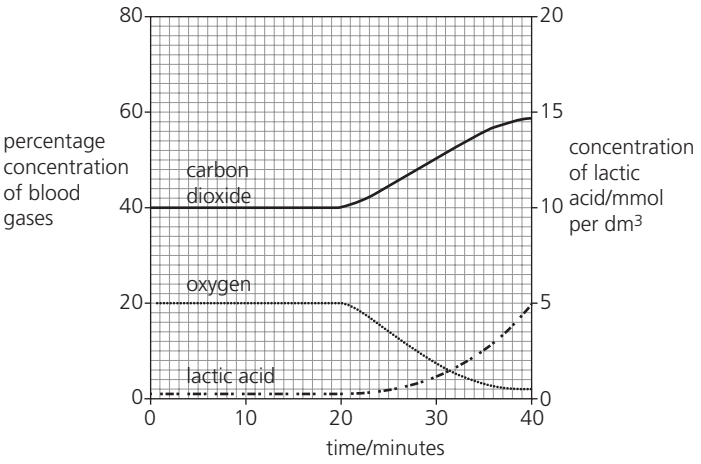
b State how aerobic and anaerobic respiration differ. [2]

c Describe a commercial use of anaerobic respiration. [5]

[Total: 10]

Cambridge O Level Biology 5090, Paper 2, Question 8, October/November 2008

3 A seal is a mammal that spends most of its time in the sea. It breathes and respires in a very similar way to a human, but when it dives to hunt and catch fish, it is capable of staying under water for up to 20 minutes.
The graph shows the percentage concentrations of oxygen and carbon dioxide, and the concentration of lactic acid in a seal's blood over a 40 minute period during which it dives to hunt and catch fish.



▲ **Figure 10.1**

a State the chemical process that is taking place in the seal's muscles before it dives. [2]

b **i)** State how long after the start of the time period the seal begins its dive. [1]

ii) State the percentage of oxygen in the seal's blood 40 minutes after the start of the time period. [1]

c Name the chemical process which starts to take place in the seal's muscles during its dive and explain how the graph supports your answer. [3]

d Suggest and explain what would happen to the concentration of lactic acid in the seal's blood when it returns to the surface of the sea after its dive. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 1, May/June 2019

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

4 **a** State the balanced equation for aerobic respiration. [2]

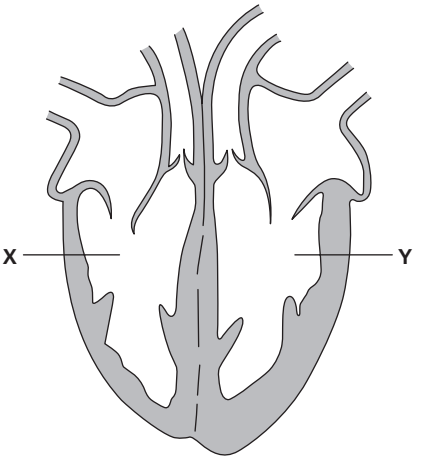
b **i)** Describe how an oxygen debt can build up in the muscles of an athlete. [3]

ii) Outline how this oxygen debt can be removed. [4]

[Total: 9]

11 Transport in humans

1 Figure 11.1 shows a vertical section through a human heart viewed from the front. Two chambers, **X** and **Y**, are labelled.



▲ **Figure 11.1**

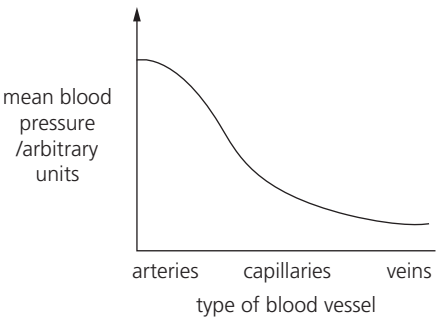
a Use Figure 11.1, and your knowledge of the circulatory system, to complete Table 11.1.

▼ **Table 11.1**

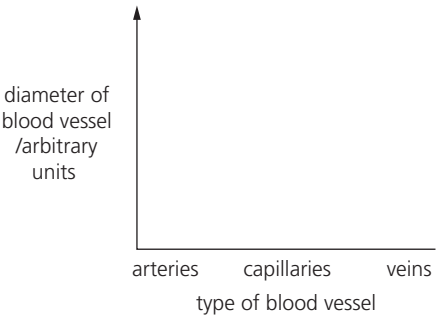
chamber	name of chamber	name of blood vessel carrying blood from chamber
X		
Y		

[4]

b Figure 11.2a shows how the mean blood pressure changes as blood flows through different types of blood vessel after leaving the heart.



▲ **Figure 11.2a**

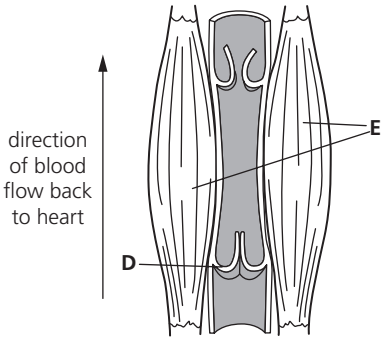


▲ **Figure 11.2b**

i) Draw a line on a copy of Figure 11.2b to show how the diameters of the vessels that blood flows through vary. [2]

ii) Use the line you have drawn on Figure 11.2b, and your biological knowledge, to explain why the mean blood pressure is higher in an artery than in a vein. [4]

c Figure 11.3 shows blood returning to the heart at low pressure through a vein in a leg.



▲ **Figure 11.3**

i) Name part **D** in Figure 11.3.
Explain how this part enables blood to return to the heart. [2]

ii) Suggest how the parts labelled **E** in Figure 11.3 help blood to return to the heart. [2]

[Total: 14]

Cambridge O Level Biology 5090, Paper 21, Question 2, October/November 2015

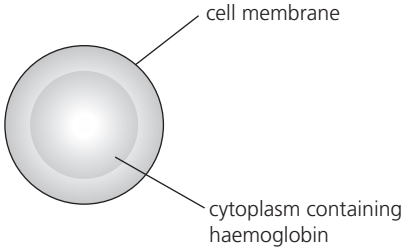
2 a Describe the double circulation of blood in the human circulatory system and the different functions of the two circuits. [6]

b Describe the structure of a capillary and the transfer of a **named** material between capillaries and tissue fluid. [4]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 8, October/November 2016

3 Figure 11.4 shows a human cell.



▲ **Figure 11.4**

a Name and state the main function of the type of cell shown in Figure 11.4. [2]

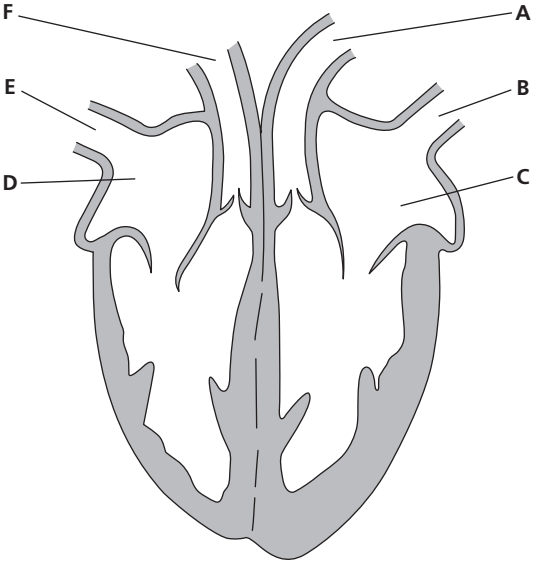
b Suggest and explain what symptoms might be experienced by a person with an unusually low number of this type of cell. [4]

c Explain what would happen to the cell shown in Figure 11.4 if placed in pure water. [3]

[Total: 9]

Cambridge O Level Biology 5090, Paper 21, Question 4, October/November 2017

4 The diagram shows a human heart and associated blood vessels.



▲ **Figure 11.5**

a Copy and complete the table to show which of the parts **A** to **F** contain oxygenated blood and which contain deoxygenated blood.
Write **each** of the letters **A** to **F** in either the right or the left side of the table.

contain oxygenated blood	contain deoxygenated blood

[2]

b i) Copy and complete the table below to show which of **A** to **F** are involved in the circulation of blood to or from each of the following locations:
- the lungs,
- the body tissues.

Write **each** of the letters **A** to **F** in either the right or the left side of the table.

blood to or from the lungs	blood to or from the body tissues

[4]

ii) Compare the pressure of blood in the circulation to the body tissues and the pressure of blood in the circulation to the lungs. [1]

iii) Explain how the structure of the heart produces this difference in blood pressure. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 4, May/June 2018

12 Disease and immunity

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

1 a Define the terms

i) *pathogen* [1]

ii) *transmissible disease*. [2]

b Copy and complete the table by naming four ways the body defends against disease and describing how each way helps to prevent infection. [8]

body defence against disease	how the defence works
1	
2	
3	
4	

[Total: 11]

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

2 a State one way in which pathogens can be spread

i) directly

ii) indirectly. [2]

b Outline four ways in which the spread of a disease can be controlled in a population. [4]

[Total: 6]

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

3 a One way in which a person can gain active immunity is by vaccination. State one other way in which active immunity can be gained. [1]

b Describe the process of vaccination. [5]

[Total: 6]

4 a i) Describe the main characteristics of a virus. [3]

ii) The human immunodeficiency virus (HIV) reproduces inside white blood cells and destroys them.
Use your knowledge of the functions of white blood cells to suggest why the virus is named the **immunodeficiency** virus. [2]

b i) HIV causes a disease called AIDS. The virus may be transmitted during sexual intercourse.
State two methods by which the spread of HIV by sexual intercourse may be controlled. [2]

ii) HIV may be transmitted in other ways.
State **two** ways, other than during sexual intercourse, by which HIV may be transmitted. [2]

[Total: 9]

Cambridge O Level Biology 5090, Paper 21, Question 5, May/June 2018

5 Figure 12.1a and Figure 12.1b each shows cells from the lining of the trachea. One is from a smoker and one is from a non-smoker.

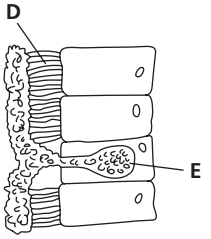


Figure 12.1a

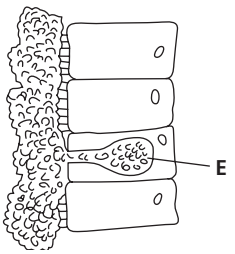
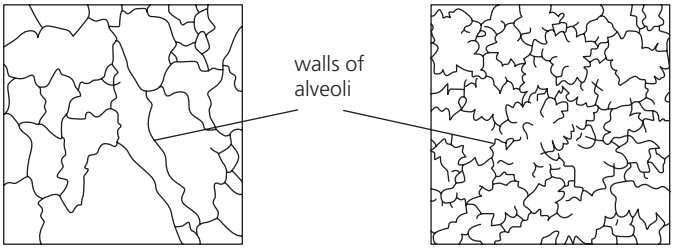


Figure 12.1b

a i) Identify **D** and **E** in Figure 12.1a. [2]

ii) Describe the function of **D**. [2]

Figure 12.2a and Figure 12.2b show cross-sections through the alveoli of a smoker and of a non-smoker.



▲ **Figure 12.2a**

▲ **Figure 12.2b**

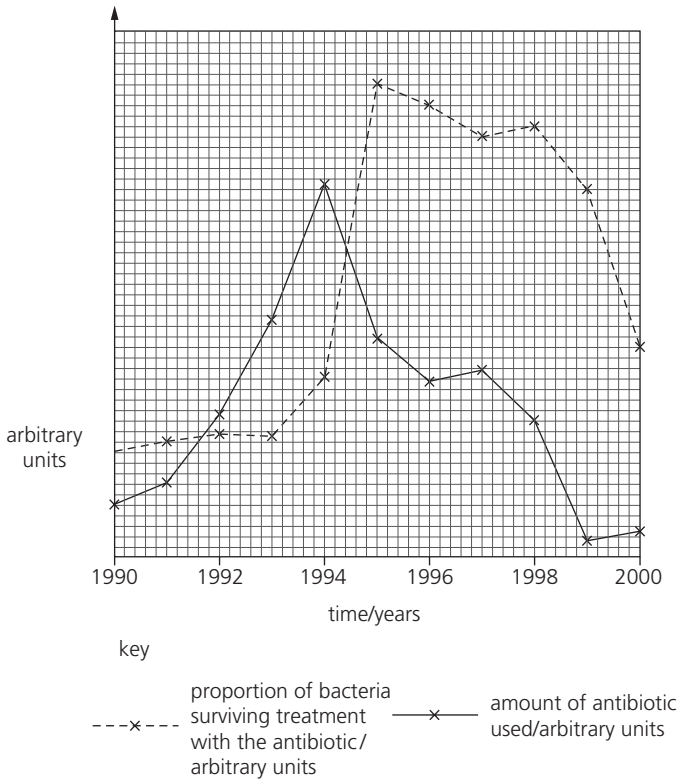
b i) Identify the figures in this question that show the trachea and alveoli of the smoker. [1]

ii) Explain how the effect of smoking on the alveoli could affect the general health of a smoker. [5]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 4, May/June 2010

6 Over a period of ten years, an antibiotic was used in a hospital to treat an infection. Figure 12.3 shows the amount of antibiotic used and the proportion of bacteria that survived treatment with the antibiotic over this period of time.



▲ **Figure 12.3**

a Name an antibiotic. [1]

b State the period of time during which the antibiotic was most effective at treating the infection in the hospital. [1]

c Suggest and explain possible causes for the increase in the proportion of bacteria that survived treatment with the antibiotic after 1994. [5]

d Suggest

i) two reasons for the decreased use of this antibiotic after 1997, [2]

ii) two possible ways of controlling the infection in the hospital after 1997. [2]

[Total: 11]

Cambridge O Level Biology 5090, Paper 2, Question 5, May/June 2009

7 Malaria is a disease caused by a parasite that is transmitted from one person to another by a vector.

a Name the vector of the parasite that causes malaria. [1]

b i) Spread of the vector may be controlled by using an insecticide.
State **two** other ways of controlling the spread of the vector. [2]

ii) Resistance to the insecticide can appear in the vector population.
Describe how the process of natural selection may bring about resistance of the vector to insecticide. [4]

[Total: 7]

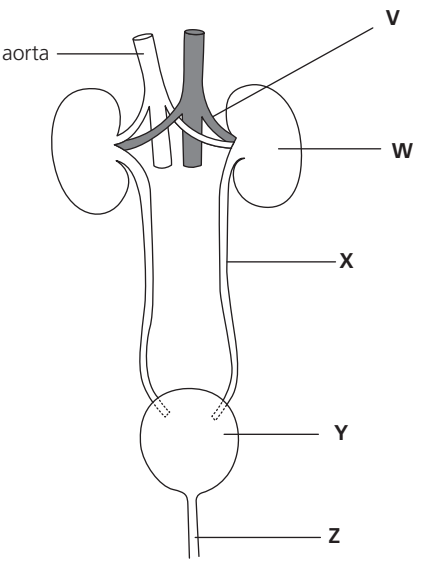
Cambridge O Level Biology 5090, Paper 21, Question 5, May/June 2016

13 Excretion

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

1 a Define the term *excretion*. [2]

b The diagram shows the human urinary system. Copy and complete the table by naming the labelled structures and stating their functions. [10]



▲ **Figure 13.1**

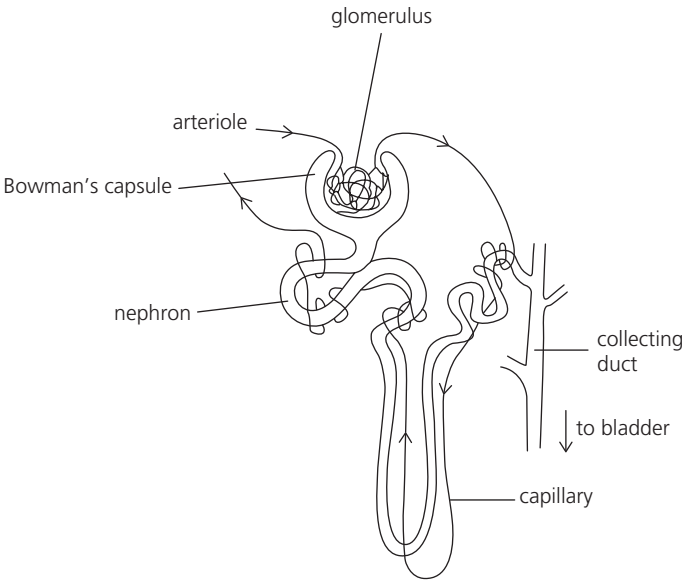
structure	name of structure	function
V		
W		
X		
Y		
Z		

[Total: 12]

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

2 **a** Explain the need for an excretory system. [2]

b The diagram shows the structure of a nephron and structures it is associated with in a kidney.



▲ **Figure 13.2**

State the functions of the following parts:

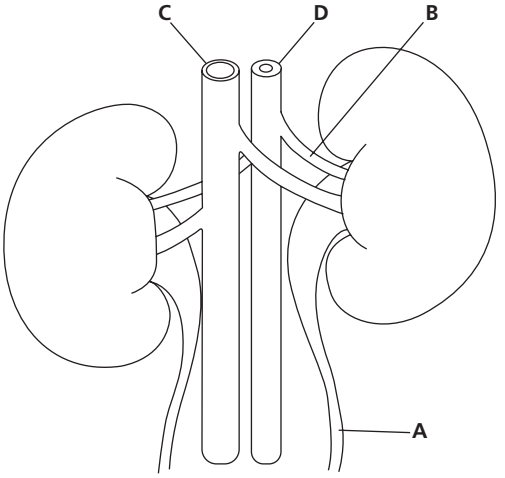
i) glomerulus [1]

ii) nephron. [3]

c The collecting duct contains urine. State what urine contains. [3]

[Total: 9]

3 Figure 13.3 shows a pair of kidneys and some associated structures.



▲ **Figure 13.3**

a **i)** Identify structure **A** in Figure 13.3. [1]

ii) Peristalsis occurs continually in structure **A**. Describe and explain how this helps the structure to carry out its function. [3]

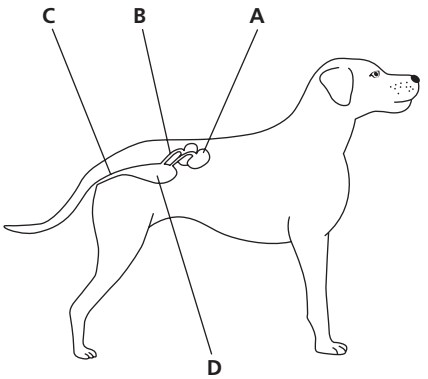
b Identify structure **B** on Figure 13.3 and state how the structural features of **C** and **D** enabled you to make your identification. [3]

c On a hot day, a person consumed **only** meat before a day of energetic work. Explain the likely changes in the composition of the person's urine during the day. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 2, Question 4, May/June 2009

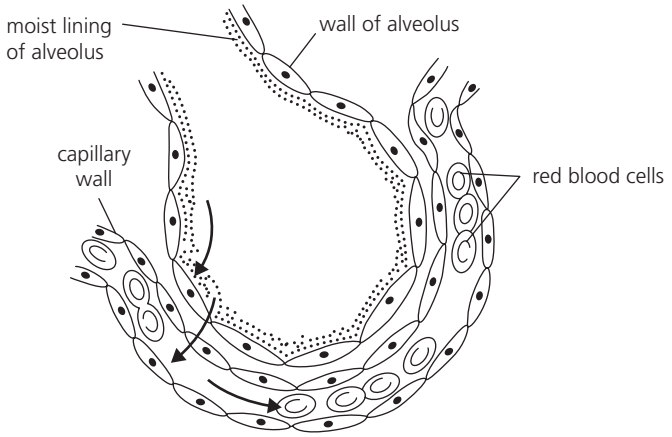
4 The urinary systems of a dog and of a human being are similar in structure and function. Figure 13.4 shows the urinary system of a dog.



▲ **Figure 13.4**

a i) Name the parts **A**, **B** and **C** in Figure 13.4. [3]
ii) State the function of **D**. [1]

b Figure 13.5 shows the relationship between an alveolus and a blood capillary in the lung of a mammal. The arrows show the path taken by oxygen from inhaled air entering the blood during gas exchange.



▲ **Figure 13.5**

i) Draw **two** arrows on a copy of Figure 13.5 to show the path taken by most carbon dioxide leaving the blood. [2]
ii) Explain why this movement of carbon dioxide is considered to be part of excretion. [3]

c Hormones are also substances that need to be excreted from the body after they have carried out their functions. Explain how this is done. [2]

[Total: 11]

Cambridge O Level Biology 5090, Paper 21, Question 1, October/November 2012

5 a State the chemical substances that are excreted by humans. [3]

b Explain how each of these substances is excreted. [7]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 8, October/November 2011

6 a Describe and explain how a protein molecule that is eaten becomes molecules of urea that are excreted. [8]

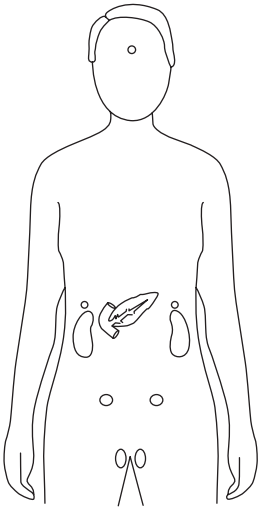
b Explain why carbon dioxide does not normally pass out of the leaves of a plant during the day. [2]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 8, October/November 2019

14 Coordination and control

1 The diagram shows the position of some organs in the human body. The organs may be found in either a male or a female, or in both.



▲ **Figure 14.1**

a Use the letters shown to label, **on a copy of the diagram**, the organs that produce the following hormones:
J – testosterone
K – insulin
L – progesterone
M – follicle stimulating hormone (FSH). [4]

b Explain how one of the hormones from **(a)** travels from the **named** organ that produces it to its **named** target organ. [4]

c Explain how the hormones progesterone and luteinising hormone (LH) are linked in the menstrual cycle. [3]

[Total: 11]

Cambridge O Level Biology 5090, Paper 21, Question 5, May/June 2019

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

2 Luteinising hormone (LH) is an example of a type of chemical substance, produced by a gland, that alters the activity of one or more specific target organs before being destroyed by the liver.

a Name this type of chemical substance. [1]

b With reference to luteinising hormone, copy and complete the table.

gland where produced	
target organ	
effect on target organ	

[3]
[Total: 4]

3 a A person looks up from focusing on a near object to focus on an object further away. Describe how changes that take place in **named** components of the person's eye produce a focused image of the distant object. [6]

b Suggest why these changes that take place in the eye are controlled by the nervous system, rather than by a hormone. [4]
[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 7, October/November 2015

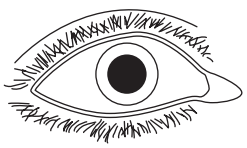
4 a Define the term *hormone*. [3]

b i) State the role of the hormone insulin in controlling blood sugar concentration. [3]

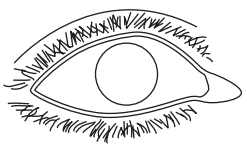
ii) Name the condition caused if a person is unable to produce sufficient amounts of the hormone insulin.
Describe the signs of the condition that you have named, and its treatment. [4]
[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 7, October/November 2016

5 Figure 14.2a shows the right eye of a person **before** moving into an area of bright light.



▲ **Figure 14.2a**



▲ **Figure 14.2b**

a i) Copy and complete Figure 14.2b to show the appearance of the right eye of the person shortly **after** moving into an area of bright light. [1]

ii) With reference to **named** structures within the eye, describe the changes that take place when a person moves into an area of bright light. [5]

b Name the type of action that occurs to make the changes that you have described and suggest why it is important that these changes take place. [4]
[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 6, October/November 2017

6 a Explain the concept of control by negative feedback. [4]

b Describe how **two named** components of the skin are involved in regulating body temperature in **hot** conditions. [6]
[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 9, May/June 2018

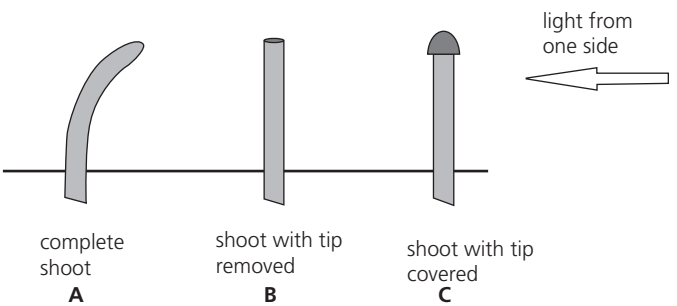
15 Coordination and response in plants

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

1 Three plant shoots were selected which were all straight and the same length. They were set up for an experiment to study the effect of one-sided light on plant growth.

- Shoot **A** was untreated.
- Shoot **B** had its tip removed.
- The growing tip of shoot **C** was covered with an aluminium foil cap.

The three shoots were then exposed to one-sided light for 24 hours.
The diagram shows the results of the experiment.



▲ **Figure 15.1**

a Describe the results of the experiment. [3]

b Name the growth substance that caused the change in shoot **A**. [1]

c i) Explain the result for shoot **B**. [2]

ii) Explain why shoot **C** did not behave in the same way as shoot **A**. [2]
[Total: 8]

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

2 a Plant growth substances are sometimes called hormones. Using your knowledge of animal hormones, suggest two reasons why it is incorrect to describe plant growth substances as hormones. [2]

b When a plant root is placed horizontally, it starts to grow downwards.

i) Name this type of response. [1]

ii) Explain how the root starts to grow downwards. [4]

[Total: 7]

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

3 a Define the term *phototropism*. [1]

b You are provided with several young plant shoots and a sample of auxin.

i) Describe an investigation you could carry out to show that auxin causes bending in a shoot. [4]

ii) Explain the mechanism that results in a shoot bending towards light. [3]

[Total: 8]

16 Development of organisms and continuity of life

1 The statements **E** to **K** relate to the process of reproduction.

E produces genetically identical offspring
F produces more individuals of the same species
G involves only one parent
H involves fusion of nuclei
I requires gametes
J forms a diploid zygote
K involves only cell division by mitosis

Table 16.1 shows a comparison of sexual and asexual reproduction.

▼ **Table 16.1**

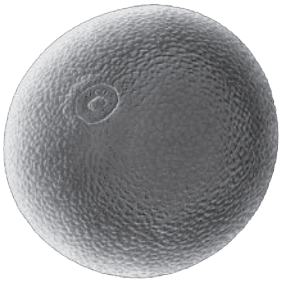
sexual reproduction only	asexual reproduction only	both sexual and asexual reproduction
	E	

Copy and complete Table 16.1 by writing each letter in the correct box to match it to sexual reproduction only, asexual reproduction only, or to both.
The first letter has been written in the correct box for you. Use each letter once only. [6]

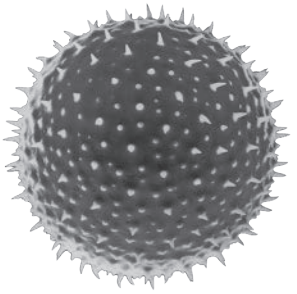
[Total: 6]

Cambridge O Level Biology 5090, Paper 21, Question 5, May/June 2017

2 Figure 16.1 shows a magnified pollen grain from each of two plant species, **A** and **B**.



magnification × 830
pollen grain from plant species **A**



magnification × 200
pollen grain from plant species **B**

▲ **Figure 16.1**

a i) Use the information in Figure 16.1 and your biological knowledge to describe **three** differences between the pollen grains from species **A** and species **B**.
Write your answers in a copy of Table 16.2. [3]

▼ **Table 16.2**

pollen grain from species **A**	pollen grain from species **B**

ii) Cross-pollination takes place in both species **A** and species **B**.
Describe what is meant by the term *cross-pollination*. [3]

iii) Using the information provided by Figure 16.1, describe how cross-pollination is most likely to occur in species **A** and in species **B**. [3]

b Figure 16.2 is a photograph of the flowers of species **A**.

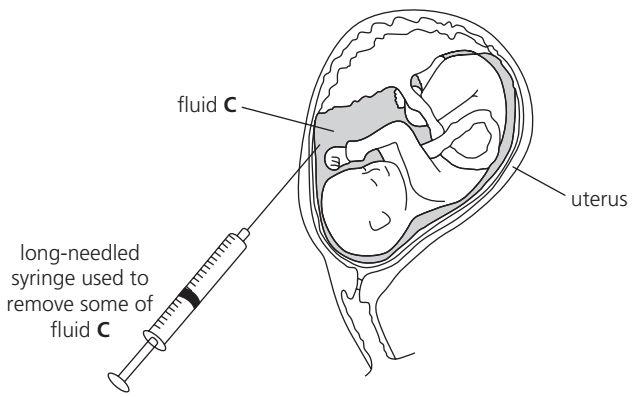
▲ **Figure 16.2**

List **two** features that would be present in the flowers of species **B** that are **not** present in those of species **A**. [2]

[Total: 11]

Cambridge O Level Biology 5090, Paper 21, Question 2, October/November 2016

3 Figure 16.3 shows a fetus developing in the uterus of a mother. The fluid labelled **C** contains cells from the fetus.
A long, hollow needle may be used to withdraw some of the fluid into a syringe. The DNA from the cells in this fluid can then be analysed to find the sex of the fetus and to detect mutations.



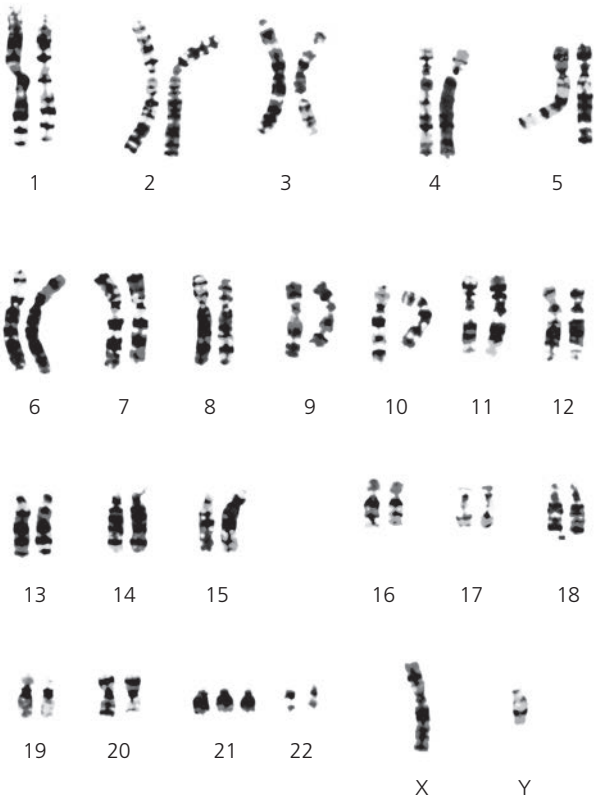
▲ **Figure 16.3**

a Name fluid **C** and state its function. [2]

b **i)** Label the placenta on a copy of Figure 16.3 using a line and the letter **P**. [1]

ii) State **two** functions of the placenta. [2]

c Figure 16.4 shows the chromosomes found in the nucleus of one cell of a developing fetus.



▲ **Figure 16.4**

State the sex of this fetus and explain your answer. [2]

d This fetus has a mutation.

i) Describe the mutation shown in Figure 16.4. [2]

ii) Suggest the condition that this child could be born with as a result of this mutation. [1]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 3, May/June 2015

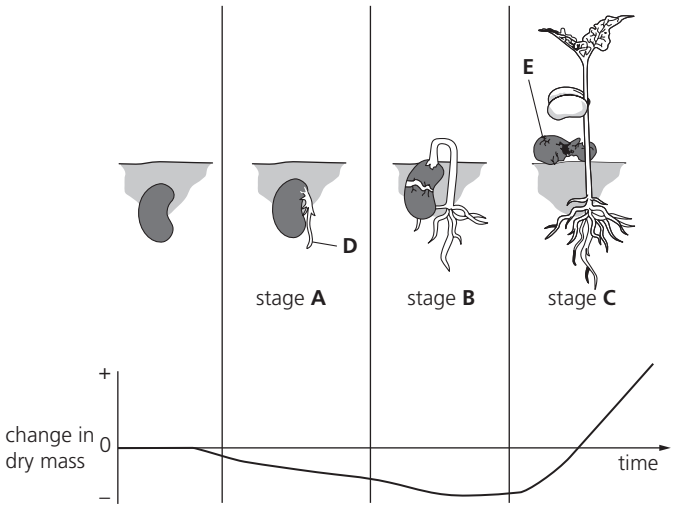
4 **a** Describe the external features of **one named** example of a wind-dispersed fruit or seed. State the importance to the plant of this method of dispersal. [5]

b State **two** environmental conditions that affect the germination of seeds. Describe the importance of each condition. [5]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 8, May/June 2015

5 Dry mass is the mass of all chemicals, excluding water, present in an organism.
Figure 16.5 shows the stages of germination of a seed. Figure 16.5 also shows the changes in dry mass of the plant during these stages of germination.



▲ **Figure 16.5**

a Name the parts labelled **D** and **E** in Figure 16.5. [2]

b Describe and explain the changes in dry mass shown during each of the stages **A**, **B** and **C** in Figure 16.5. [6]

c Water is needed for germination of seeds. State **two** other conditions needed for germination. Explain why each condition is needed. [4]

[Total: 12]

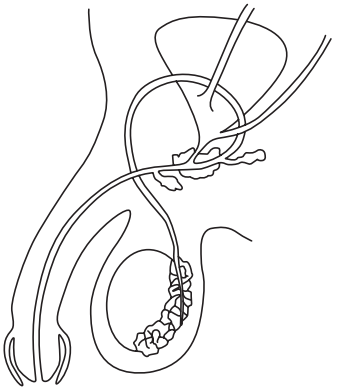
Cambridge O Level Biology 5090, Paper 21, Question 2, May/June 2016

6 The diagram shows a male human gamete.

▲ **Figure 16.6**

a i) State the name of the male human gamete. [1]

The diagram below shows the male reproductive system and associated organs.



▲ **Figure 16.7**

ii) Label with a letter **X** on the diagram where the male gametes are produced. [1]

iii) The nucleus of the male gamete is different from the nuclei of other types of cell found at location **X**.
State the cause of this difference and explain its importance in reproduction. [3]

b Describe the differences in size and mobility between the male human gamete and the female human gamete. [2]

c Copy and complete the paragraph by writing the most appropriate word in each of the spaces.
The fusion of a male human gamete and a female human gamete to form a ..... is called ..... . A ball of cells is then formed that becomes implanted in the wall of the ..... . [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 2, May/June 2018

17 Inheritance

1 Copy and complete the paragraph below by writing the most appropriate word in each of the spaces.
A ..... includes a long molecule of DNA that is divided into sections called genes. Genes may be copied and passed on to the next generation. Each gene may have two or more alternative forms called ..... . One of these forms may be ..... and the other recessive. A change in the structure of a gene or in the number of chromosomes is called

a ..... . Chemicals and ..... may increase the rate at which these changes take place. [5]

[Total: 5]

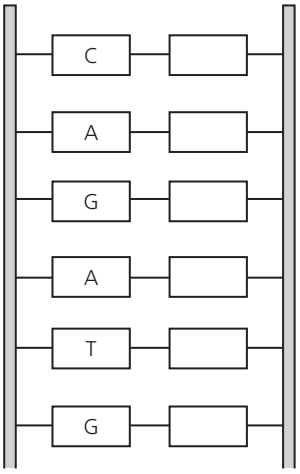
Cambridge O Level Biology 5090, Paper 21, Question 5, October/November 2016

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

2 **a** Describe the structure of a DNA molecule. [3]

b Outline how DNA controls cell function. [3]

c The diagram shows part of a DNA molecule.



▲ **Figure 17.1**

i) Copy and complete the diagram by writing the letters of the missing bases. [4]

ii) Explain why the sequence of bases is important. [2]

[Total: 12]

3 Figure 17.2 shows a Bengal tiger.

▲ **Figure 17.2**

(This image differs from the original image but has been approved as a suitable replacement.)

Fur colour in the Bengal tiger is controlled by a single gene. The dominant allele of the gene results in orange fur. A single change in this gene produces a recessive allele, which results in white fur in tigers with the homozygous recessive genotype.

a **i)** Define the term *gene*. [3]

ii) State the term used to describe a change in a gene. [1]

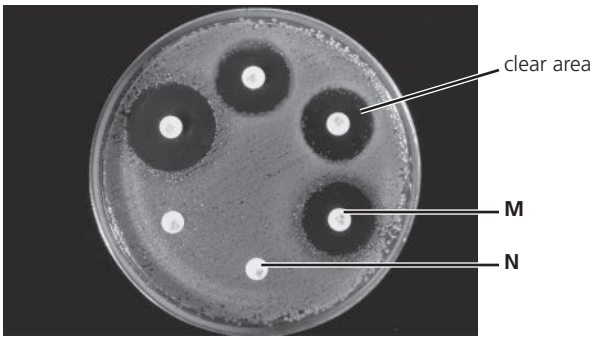
b Using the letters **T** (orange) and **t** (white) to represent the alleles that control fur colour, draw a labelled genetic diagram to show how two tigers with orange fur may give rise to offspring with white fur. [5]

c Bengal tigers have dark stripes on their fur. Suggest why each of the following is true for the pattern of dark stripes:
it is **not** affected by whether the fur is orange or white
it is unique to each individual. [3]

[Total: 12]

Cambridge O Level Biology 5090, Paper 21, Question 4, May/June 2017

4 Figure 17.3 shows bacteria growing on the surface of a dish containing nutrient jelly. Paper discs, such as **M** and **N**, were soaked in solutions of different antibiotics and placed on top of the growing bacteria. A clear area on the jelly indicates that bacteria in that area have been killed.



▲ **Figure 17.3**

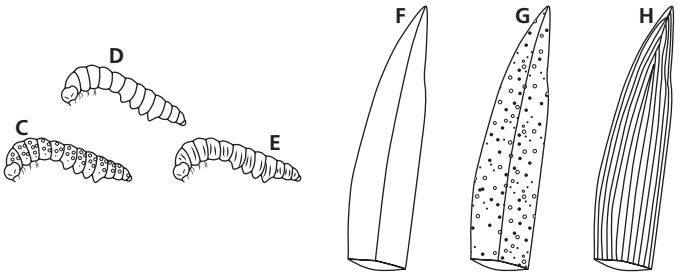
a Use the information above, and your knowledge of the process of natural selection, to describe and explain the difference in appearance of the jelly surrounding discs **M** and **N**. [6]

b Describe how the process of artificial selection differs from that of natural selection. Include reference to the production of **one named** economically important plant or animal in your answer. [4]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 7, May/June 2017

5 The diagram shows three varieties, **C**, **D** and **E**, of the same species of insect, and three different leaf patterns, **F**, **G** and **H**, of the same species of plant on which the insect feeds.



▲ **Figure 17.4**

a Suggest which variety of the insect is likely to be found in the greatest numbers in areas where leaf pattern **G** of the plant is found, and explain your answer. [2]

b Over a period of many years, as they grow, the plants lose the dots and stripes on their leaves which become plain. Suggest and explain what is likely to happen to the numbers of the different varieties of insect in an area where the majority of plants are old. [4]

c Two alleles, **T** and **t**, control the body pattern of the insects.
Insects with dots (**C**) are homozygous dominant.
Insects with stripes (**E**) are homozygous recessive.
Plain insects (**D**) are heterozygous.
Explain why all three varieties of insect will continue to be produced even in areas where all the plants have plain leaves. [4]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 2, May/June 2019

6 Describe and compare the following:

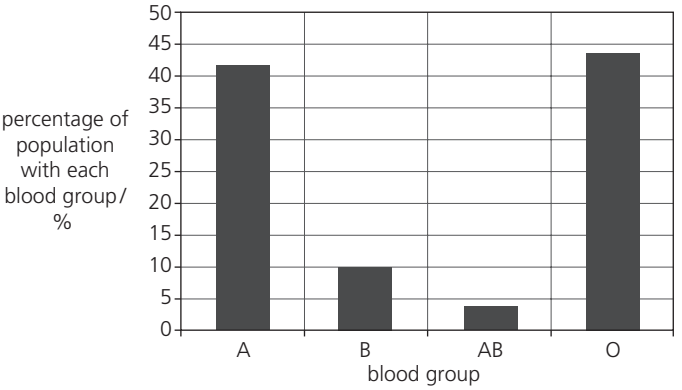
a gene and allele [5]

b continuous variation and discontinuous variation. [5]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 8, May/June 2019

7 a Figure 17.5 shows the distribution of blood groups in the population of a country.



▲ **Figure 17.5**

i) State the type of variation shown in Figure 17.5. [1]

ii) Give a reason for your answer to part **(a)(i)**. [1]

iii) The population of this country is approximately 63 million people. Use the information in Figure 17.5 to calculate the approximate number of people in the country that have **blood group B**.
Show your working. [2]

b Table 17.1 shows the distribution of blood groups in the populations of four countries.

▼ **Table 17.1**

Country	percentage of population with each blood group (%)			
	A	B	AB	O
S	23	38	10	29
T	42	10	4	44
U	26	18		52
V	36	14	4	46

i) Calculate the percentage of the population of country **U** that has blood group AB.
Write your answer in the space provided in a copy of Table 17.1. [1]

ii) Suggest why the percentage of the population with each blood group varies between the countries listed. [2]

c Suggest why it might be necessary to know a person's blood group. [2]

d A child's mother has blood group AB and the child's father has blood group O. Draw a ring around each possible genotype and blood group of the child.

genotypes	I^AI^A	I^AI^O	I^BI^B	I^BI^O	I^AI^B	I^OI^O
blood groups	A	B	AB	O		

[2]

[Total: 11]

Cambridge O Level Biology 5090, Paper 21, Question 3, October/November 2015

18 Biotechnology and genetic modification

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

1 a Explain why bacteria are useful in biotechnology and genetic modification. [2]

b Outline the use of enzymes in

i) the production of fruit juices [3]

ii) the use of biological washing powders. [3]

[Total: 8]

(This is an exam-style question that was written by the author of this book and is not from a past paper.)

2 a Define the term *genetic modification*. [2]

b Outline the process of using bacteria to produce human insulin. [6]

[Total: 8]

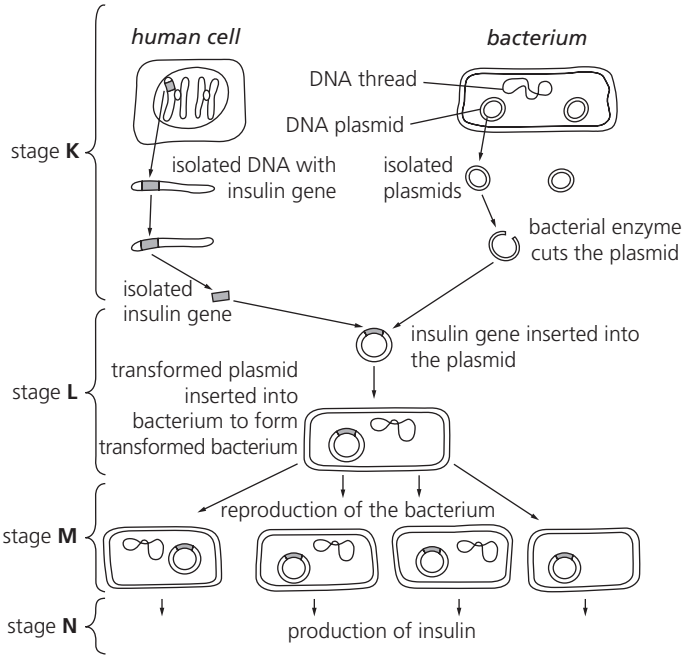
3 a Describe and explain how microorganisms are used to produce a hormone commercially. [7]

b State the advantages of obtaining hormones by this method. [3]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 6, October/November 2011

4 Figure 18.1 shows the stages in the process of genetic engineering (modification) to produce the hormone insulin.



▲ **Figure 18.1**

a i) Describe how the location and organisation of genetic material in the human cell shown in stage **K** of Figure 18.1 is different from that in the bacterial cell shown. [3]

ii) Use your knowledge of bacterial cells to name **two** structures that the transformed plasmid must pass through to form a transformed bacterium in stage **L** of Figure 18.1. [2]

iii) State the type of reproduction that takes place in stage **M** of Figure 18.1. Use your knowledge of the process of cell division to explain why it is important that this type of reproduction occurs. [3]

iv) Name the condition in humans that is treated using insulin produced by the bacteria in stage **N** of Figure 18.1. [1]

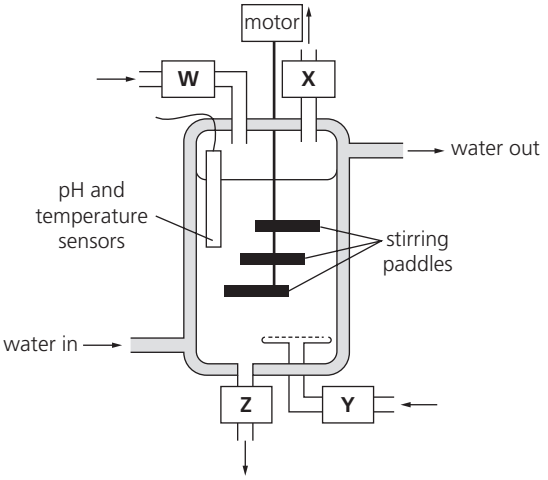
v) Stage **N** of Figure 18.1 may take place in a container similar to that used in the large-scale production of antibiotics. State the name of this type of container. [1]

b Genetic engineering (modification) can also be used to produce crop plants for humans to eat. Discuss the potential advantages and dangers of using genetic engineering (modification) to produce crop plants for humans to eat. [4]

[Total: 14]

Cambridge O Level Biology 5090, Paper 21, Question 4a(i–v) & b, May/June 2016

5 Figure 18.2 shows a fermenter used for the production of an antibiotic.



▲ **Figure 18.2**

a i) Identify what enters or leaves through each of **W**, **X**, **Y** and **Z** in Figure 18.2. [4]

ii) Explain the importance of the substance entering through **Y** in the production of the antibiotic. [2]

b Explain why it is important to detect and to control the pH and temperature of the contents of the fermenter. [3]

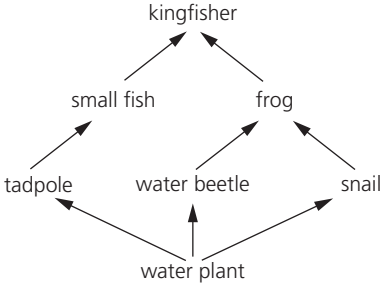
c Suggest **one** advantage of the motor being located outside, rather than inside, the reaction vessel of the fermenter. [1]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 7, October/November 2017

19 Relationships of organisms with one another and with the environment

1 The diagram shows a food web in a pond.



▲ **Figure 19.1**

a i) Copy and complete the table by writing the correct number of organisms for each statement about the food web. The first number has been written for you.

statement	number
the number of producers	1
the number of consumers	
the number of herbivores	
the number of carnivores	
the number of food chains	

[4]

ii) Draw and label a pyramid of biomass for **one** food chain from the food web. [2]

b The pond may become polluted by fertilisers containing nitrogen.
Explain how this pollution might affect the population of frogs in the pond. [4]

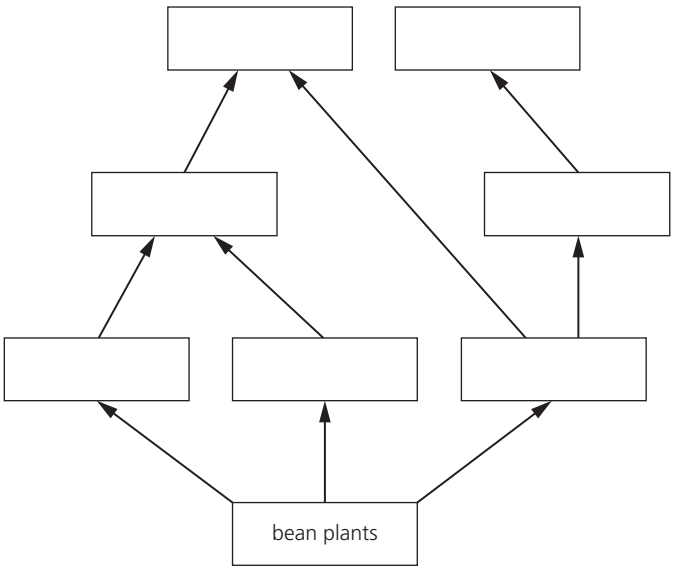
[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 1, May/June 2018

2 Over a period of several months, a student recorded some activities of the wild life in a particular habitat. The following observations appeared in her notebook.

1. Young shoots of a crop of bean plants covered with greenflies (aphids) sucking food from the stems.
2. Saw a large bird (hawk), which usually catches mice, swoop to take a small yellow bird clinging to a bean stem. Noticed that these small birds often visit the bean field to eat some of the aphids or butterflies.
3. Flowers of beans being visited by many different species of butterfly.
4. Mice seen nibbling at some dispersed bean seeds.
5. Spider's web constructed between two bean plants with 5 large black flies caught in it. Rotting body of a mouse nearby attracting similar flies.

a Copy and complete Figure 19.2 by filling in the names of the organisms to show the feeding relationships in this community.



▲ **Figure 19.2**

[4]

b i) What name is given to a chart of feeding relationships as shown in Figure 19.2? [1]

ii) Name two top carnivores observed by the student. [2]

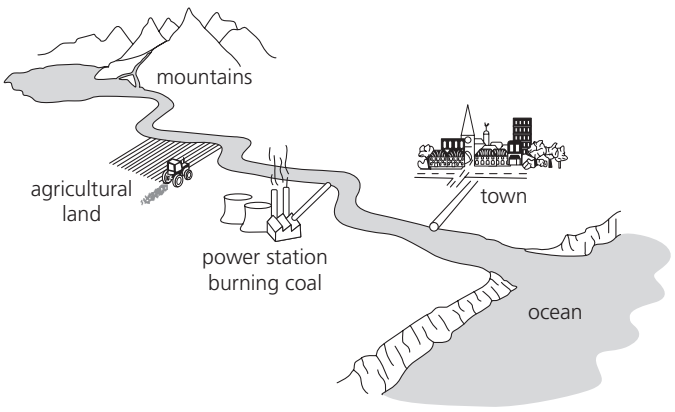
c i) Draw and label a pyramid of biomass for the hawks, mice and bean plants in this habitat. [2]

ii) Draw and label a pyramid of numbers for a bean plant, small birds and aphids. [2]

[Total: 11]

Cambridge O Level Biology 5090, Paper 2, Question 3, May/June 2008

3 The diagram shows the location of several features close to a river that runs from mountains into the ocean.



▲ **Figure 19.3**

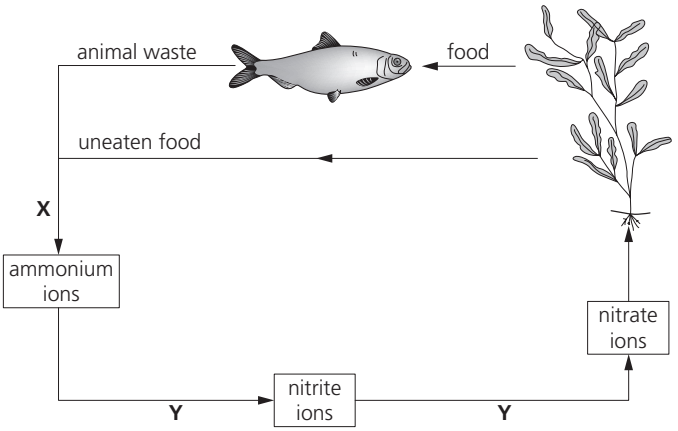
a Describe and explain the possible harmful effects of human activity on the environment at each of the following locations:
the agricultural land,
the power station. [6]

b Suggest ways in which people in the town could make changes to their activities in order to reduce the harmful impact that they have on the environment. [4]

[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 6, October/November 2018

4 Figure 19.4 shows some of the interactions that take place in an aquatic ecosystem.



▲ **Figure 19.4**

a i) Use the information in Figure 19.4 to state each of the following:
- the trophic level of the aquatic plant
- the trophic level of the fish
- the chemical element being cycled in this ecosystem. [3]

ii) Explain **one** way, other than for food, that the fish may depend on the aquatic plant. [2]

b i) Name each of the processes represented by the letters **X** and **Y**. [2]

ii) Name **one** type of microorganism that will carry out **both** process **X** and process **Y**. [1]

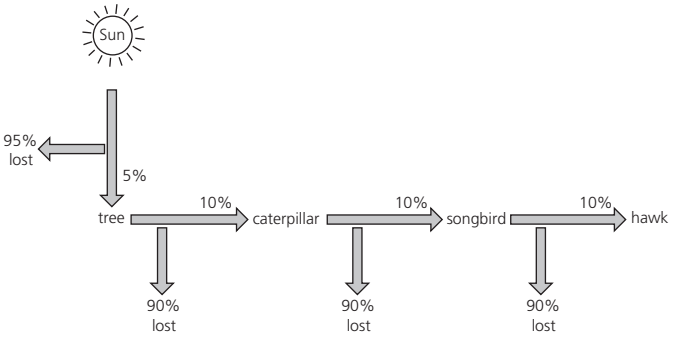
iii) Explain how aquatic plants take up nitrate ions from their surroundings. [3]

c Suggest what effect pollution by nitrogen-containing fertilisers might have on this ecosystem. [2]

[Total: 13]

Cambridge O Level Biology 5090, Paper 21, Question 5, May/June 2015

5 Figure 19.5 shows the flow of energy within a biological system.



▲ **Figure 19.5**

a i) Name the type of chart shown in Figure 19.5. [1]

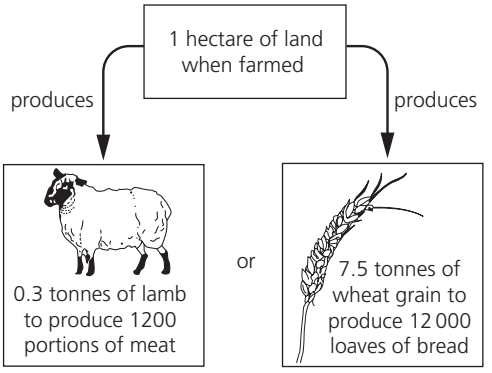
ii) Name **one** example, shown in Figure 19.5, of each of the following types of organism.

- producer
- carnivore [2]

b i) Suggest why only 5% of the energy from the Sun passes to the tree. [2]

ii) Describe how energy is lost between the songbird and the hawk. [3]

c Figure 19.6 shows two possible uses of the same area of land to produce food.



▲ **Figure 19.6**

Use the information in Figure 19.5 and Figure 19.6, and your own knowledge, to explain why it is possible to feed a greater number of people if the area of land is used to farm crops rather than to farm animals. [5]

[Total: 13]

Cambridge O Level Biology 5090, Paper 21, Question 3, October/November 2017

6 a Explain how energy from the Sun can eventually be used for active transport in the alimentary canal. [7]

b Solar energy is increasingly being used to replace fossil fuels to generate electricity. Explain the **disadvantages** of continuing to use fossil fuels to generate electricity. [3]

[Total 10]

Cambridge O Level Biology 5090, Paper 21, Question 7, October/November 2019

7 a Describe and explain how a nitrate ion in the soil becomes part of a stored molecule in the seed of a plant. [8]

b Explain why water is essential for the process of seed germination. [2]

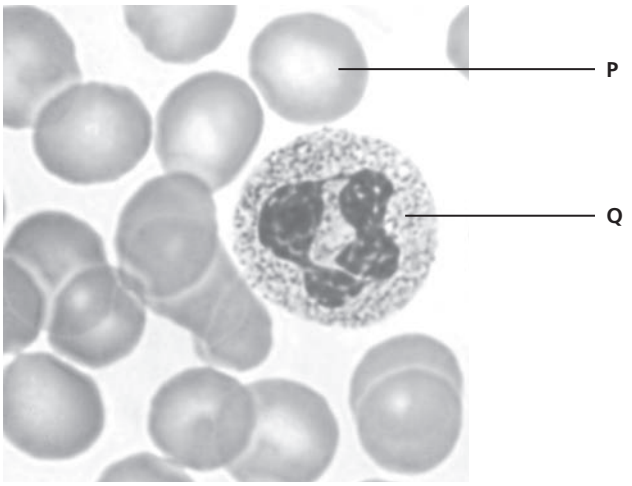
[Total: 10]

Cambridge O Level Biology 5090, Paper 21, Question 9, October/November 2019

Alternative to practical past paper questions

1 Cells

1 Figure 1.1 shows blood cells as seen using a light microscope.



▲ **Figure 1.1**

a Make a drawing of the cell labelled **Q** in Figure 1.1, magnified × 2.
You do not need to label your drawing. [4]

b
i) Identify cell **P** and cell **Q**. [2]
ii) Use Figure 1.1 to describe how the appearance of cell **Q** differs from that of cell **P**. [1]

c Figure 1.2 shows a plant cell as seen using a light microscope.

▲ **Figure 1.2**

(This image differs from the original image but has been approved as a suitable replacement.)

Copy and complete Table 1.1 to compare cell **Q** in Figure 1.1 and the plant cell in Figure 1.2.

▼ **Table 1.1**

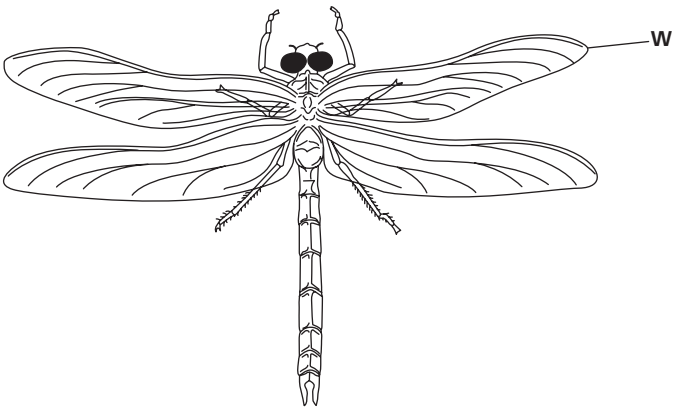
feature	cell Q	plant cell
cell wall		
nucleus		

[2]
[Total: 9]

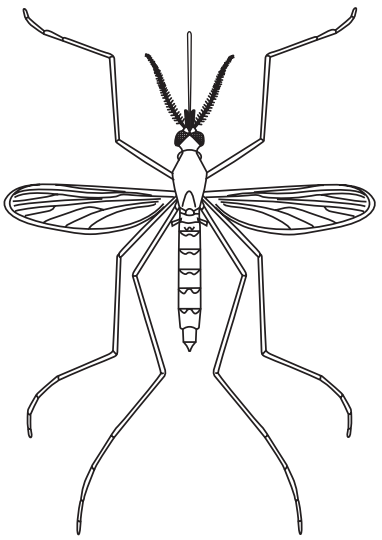
Cambridge O Level Biology 5090, Paper 61, Question 2, May/June 2017

2 Classification

1 Figures 2.1 and 2.2 show two different insects.



▲ **Figure 2.1**



▲ **Figure 2.2** (Not drawn to the same scale)

a List four **visible** features that are the same in both insects. [4]

b Copy and complete Table 2.1 with four pairs of differences that are **visible** in these insects.

▼ **Table 2.1**

	feature in Figure 2.1	same feature in Figure 2.2
1		
2		
3		
4		

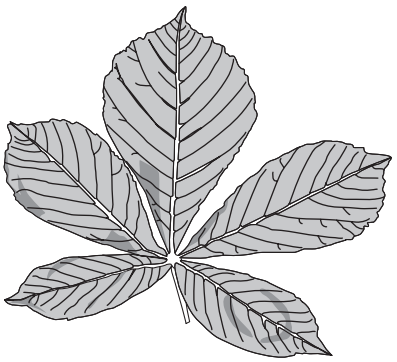
[4]

c In the specimen from which Figure 2.1 was made, the length of the wing labelled **W** was 40 mm.
Calculate the magnification of the insect shown in Figure 2.1.
Show your working clearly. [3]

[Total: 11]

Cambridge O Level Biology 5090, Paper 61, Question 2, October/November 2010

2 Figure 2.3 shows leaves from four different trees: horse chestnut, laurel, hornbeam and oak.



horse chestnut

laurel

hornbeam

oak

▲ **Figure 2.3**

a Make a large drawing of the horse chestnut leaf.
You do not need to label your drawing. [5]

b There are several differences between these leaves, which can be used to identify each leaf.
Copy and complete Table 2.1 by describing the overall shape and the edge (margin) of the laurel leaf and the oak leaf. The shape and edge of the hornbeam have been described for you.

▼ **Table 2.1**

feature	**tree**		
	hornbeam	**laurel**	**oak**
shape	oval		
edge (margin)	serrated		

[4]

c **i)** The actual maximum width of the laurel leaf is 40 mm. Measure and record the maximum width of this leaf in Figure 2.3.
Draw a line on a copy of Figure 2.3 to show where you have taken this measurement. [2]

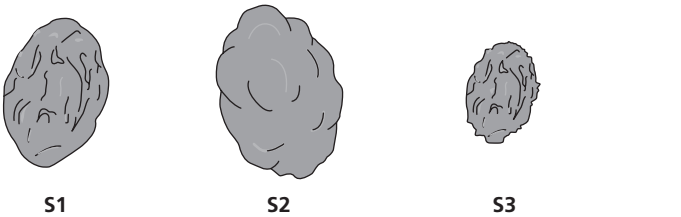
ii) Calculate the magnification of the laurel leaf in Figure 2.3. Show your working. [2]

[Total: 13]

Cambridge O Level Biology 5090, Paper 61, Question 2, May/June 2016

3 Movement into and out of cells

1 Figure 3.1 shows three sultanas labelled **S1**, **S2**, **S3**. Sultanas are grapes that have been dried in the sun.



S1 **S2** **S3**

magnification x4

▲ **Figure 3.1**

S1 is a sultana. **S2** was a similar sized sultana that had been left to soak in water for twenty-four hours. **S3** was a similar sized sultana that had been left to soak in concentrated sugar solution for twenty-four hours.

a **S1** gave a positive result when tested for reducing sugar.

i) Describe how you would test **S1** for reducing sugar. [3]

ii) Describe a positive result. [1]

b In terms of water potential, explain what you think has happened to **S2** while it was soaking in the water. [3]

c Figure 3.2 is a photograph of a section from a different fruit.

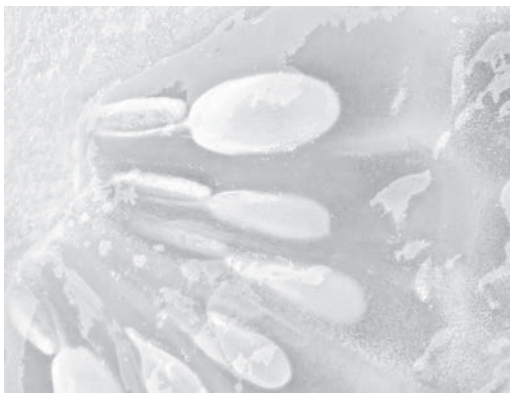
magnification × 1.5

▲ **Figure 3.2**

(This image differs from the original image but has been approved as a suitable replacement.)

i) Make a large labelled drawing of the section shown in Figure 3.2. [5]

Figure 3.3 is an enlargement of part of Figure 3.2.



▲ **Figure 3.3**

(This image differs from the original image but has been approved as a suitable replacement.)

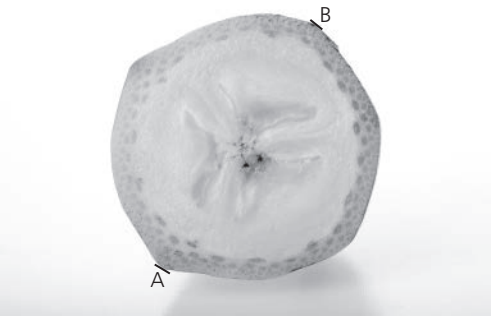
ii) Calculate the magnification of Figure 3.3. Indicate on a copy of both photographs where your measurements were taken. Show your working. [3]

[Total: 15]

Cambridge O Level Biology 5090, Paper 6, Question 2, May/June 2006

4 Biological molecules

1 The banana is the fruit of a banana plant. As the fruit gets older, it ripens and becomes easy to eat. The photograph shows a cross-section of a ripe banana.



magnification × 1.5

▲ **Figure 4.1**

a **i)** Make a large drawing of the cross-section of the banana fruit as shown in the photograph. [3]

ii) Measure the distance between the lines labelled **A** and **B** which show the diameter of the banana. Record the measurement in mm. Draw a straight line in the same position on your drawing. Measure this line on your drawing and record the measurement in mm. Calculate the magnification of your drawing in comparison with the actual banana shown in the photograph. Show your working. [5]

b In an experiment, a student cut a thin slice of banana and placed it on a white tile with the freshly cut surface facing upwards.
She covered this cut surface with iodine solution and left it for five minutes.
After five minutes she picked up the banana slice using forceps and rinsed off the excess iodine solution using water.

She observed that some of the inner parts of the banana slice were stained black.

i) State what conclusions she could make from her observations. [2]

ii) Suggest why the student rinsed off the excess iodine solution before observing the banana. [1]

iii) Suggest why she used forceps to hold the banana while rinsing off the excess iodine solution. [1]

c i) Describe how you would test the inner part of another slice of banana to see if it contains reducing sugar. [3]

ii) State the result of the test if reducing sugar is present. [1]

iii) Describe **one** way you would ensure that you carry out the reducing sugar test safely. [1]

[Total: 17]

Cambridge O Level Biology 5090, Paper 61, Question 1, October/November 2018

Glossary

Absorption (by diffusion, osmosis and active transport) The movement of nutrients from the intestines into cells lining the digestive system and then into the blood

Accommodate Changing the shape (and focal length) of the eye lens to focus on near or distant objects

Acquired immune deficiency syndrome (AIDS) A sexually transmitted infection, also passed on through infected blood and from infected mother to her baby in the uterus, during birth or through the mother's milk. It is caused by a virus called the human immunodeficiency virus (HIV)

Acrosome The tip of a sperm cell, which secretes enzymes to digest the cells around an egg and the egg membrane

Active immunity Defence against a pathogen by antibody production in the body

Active site Part of an enzyme molecule, which exactly fits the substance on which the enzyme acts. Its shape can be permanently deformed by a high temperature and extreme pH

Active transport The movement of molecules or ions into or out of a cell through the cell membrane from a region of their lower concentration to a region of their higher concentration against a concentration gradient, using energy released during respiration

Actual size The true size of an object

Adaptation The process resulting from natural selection by which populations become more suited to their environment over many generations

Adrenal gland Adrenal glands are attached to the back of the abdominal cavity, one above each kidney, and produce the hormone adrenaline

Adrenaline A hormone, secreted by the adrenal glands, which causes increased heart beat and breathing rate and depth, along with dilation of the pupils. Its effects allow us to react more quickly and vigorously in dangerous situations

Aerobic respiration The release of a relatively large amount of energy by the breakdown of glucose in the presence of oxygen

Allele An alternative form of a gene

Alimentary canal A long tube of organs, including the oesophagus, stomach and intestines, which runs from the mouth to the anus. It is involved in the digestion of food to provide the body with nutrients

Alveoli Little, thin-walled, pouch-like air sacs attached to the bronchioles in the lungs and closely associated with capillaries. Responsible for gas exchange

Amino acid Organic compound composed of nitrogen, carbon, hydrogen and oxygen. It is a sub-group of proteins and there are about 20 different amino acids in animal proteins

Amniotic fluid Fluid which surrounds the embryo as it develops, protecting it from damage and preventing unequal pressure acting on it

Amniotic sac A fluid-filled sac surrounding the embryo as it develops

Amylase Starch-digesting enzyme, secreted by the salivary glands into the mouth, and the pancreas into the duodenum

Anaerobic respiration The release of a relatively small amount of energy by the breakdown of glucose without using oxygen

Antagonistic Refers to muscles which oppose each other. For example, circular and radial muscles in the iris of the eye

Anther Contains pollen sacs in which pollen grains are formed

Antibiotic An antibacterial drug derived from a fungus or bacterium

Antibody Proteins that bind to antigens, leading to direct destruction of pathogens or marking of pathogens for destruction by phagocytes

Antigen A substance which promotes the formation of antibodies

Aorta The main artery leaving the heart, from the left ventricle, carrying oxygenated blood to the head and body

Artery (pl. Arteries) A vessel carrying blood from the heart at high pressure

Artificial insemination (AI) A means of achieving pregnancy by introducing semen into the uterus of a female. It is sometimes used in captive breeding programmes to increase numbers of an endangered species

Artificial selection A technique used by humans to produce varieties of animals and plants that have an increased economic importance

Asexual reproduction The process resulting in the production of genetically identical offspring from one parent

Assimilation The uptake and use of nutrients by cells from the blood

Atmosphere The envelope of gases surrounding the earth

Atrioventricular valve A heart valve which lies between the atrium and ventricle and prevents the back-flow of blood

Atrium (pl. Atria) The upper chamber of the heart, receiving blood from the veins

Auxin A chemical which affects the rate of growth in plants

Bacteria (sing. Bacterium) These are single-celled organisms belonging to the Prokaryote kingdom. They are different from other single-celled organisms because their chromosomes are not organised into a nucleus

Bacterial infection An infection caused by harmful bacteria

Balanced diet A diet that contains all the essential nutrients in the correct proportions to maintain good health. The nutrients needed are carbohydrate, lipid, protein, vitamins, mineral salts, fibre (roughage) and water

Base (organic) The part of a nucleotide that contains nitrogen. In DNA the bases are adenine (A), thymine (T), cytosine (C) and guanine (G)

Benedict's solution A test for the presence of reducing sugar (e.g. glucose). The solution turns from clear blue to cloudy green, then yellow, and finally to a red precipitate (deposit) of copper (1) oxide when glucose is present

Bile A green, watery fluid made in the liver. It is stored in the gall bladder and is sent to the duodenum through the bile duct. It contains no enzymes, but contains bile salts, which emulsify fats, breaking them up into small droplets with a large surface area

Binomial system An internationally agreed system in which the scientific name of an organism is made up of two parts showing the genus and species

Biodiversity The number of different species that live in an area

Biological catalyst The definition of an enzyme, which is a protein that speeds up reactions, for example, inside cells

Biomass The weight (mass) of all the organisms in a population, community or habitat

Biotechnology The use of living organisms or biological processes for industrial, agricultural or medical purposes

Bladder A hollow muscular organ that collects and stores urine from the kidneys before disposal by urination

Bowman's capsule A part of the nephron that forms a cup-shaped structured surrounding the glomerulus

Bronchi A pair of air pipes branching from the trachea and going to the lungs

Bronchiole A branch of a bronchus in the lungs which is attached to alveoli

Capillary The smallest type of blood vessel in the circulatory system. Its walls are only one cell thick to allow the exchange of materials between the blood and surrounding cells

Carnivore An animal that gets its energy by eating other animals

Carpel The female reproductive organ of a flower, consisting of a stigma, style and ovary

Catalyst A substance that increases the rate of a chemical reaction and is not changed by the reaction

Cell The smallest basic unit of an animal or plant. It is microscopic and acts as a building block

Cell membrane A thin layer of cytoplasm around the outside of a cell. It is selectively permeable, controlling what substances enter and leave the cell

Cellulose A polysaccharide made of chains of glucose units which is found in plant cell walls. It is tough and stops the cell bursting, but is freely permeable

Cement A thin layer of bone-like material covering the roots of the teeth of mammals. It enables the tooth to grip to its bony socket in the jaw

Central nervous system Part of the nervous system consisting of the brain and spinal cord

Cervix A ring of muscle separating the vagina from the uterus

Chemical digestion The breakdown of large molecules into small molecules

Chlorophyll A green chemical present in chloroplasts. It can trap light energy for photosynthesis

Chloroplast A green organelle in the cytoplasm of a photosynthesising plant cell. It contains chlorophyll to trap light energy for photosynthesis

Chromosome A thread of DNA made up of a string of genes

Chromosome mutation A change in the chromosome number or structure

Ciliary body Part of the eye that produces aqueous humour and contains ciliary muscles

Ciliary muscle The muscle in the eye which alters the shape of the lens during accommodation. It is attached to the lens and the ciliary body

Ciliated cells Cells with cytoplasmic 'hairs' called cilia, which can flick to produce movement. They are found in the nose and windpipe

Circular muscle A muscle with a ring shape, which can contract to reduce the diameter of a structure, for example, oesophagus in the digestive system or iris of the eye

Circulatory system A system of blood vessels with a pump and valves to ensure a one-way flow of blood

Classify To sort things into a meaningful order (e.g. groups of organisms)

Codominance A situation in which both alleles in heterozygous organisms contribute to the phenotype

Collecting duct Part of the kidney at the end of a nephron, which passes urine to the ureter

Collision Bumping of molecules due to kinetic energy

Community All the populations of different species in an ecosystem

Competition An interaction between organisms or species in which both the organisms or species are harmed. The competition may be for food, water, light, territory or a nesting site

Complementary A term to describe how the shape of the active site of an enzyme fits the substance on which it acts

Concentration gradient The difference in concentration on either side of a membrane. The bigger the gradient, the faster a molecule or ion will move from the higher concentration to the lower concentration

Consumer An organism that gets its energy by feeding on other organisms

Continuous variation A type of variation that results in a range of phenotypes between two extremes. Examples include body length and body mass. It is caused by a combination of a number of genes and the environment

Control Part of an experiment missing a condition to compare with the variable in which the condition is altered

Coordination The processes which make the different systems in an organism work effectively together

Cornea The transparent part of tissue at the front of the eyeball that refracts light entering the eye to help to focus it

Coronary artery A blood vessel on the surface of the heart which transports oxygenated blood to the heart muscle

Cortex 1 The outer region of the kidney, containing capillaries, glomeruli and Bowman's capsules for filtering blood. 2 A region of the root and stem of a plant inside the epidermis. In the root it transfers water and mineral ions from root hair cells to xylem vessels

Cotyledon An embryonic leaf in a seed which often contains food stores

Cross-pollination Transfer of pollen grains from the anther of a flower to the stigma of a flower on a different plant of the same species

Cuticle 1 A thin, waxy, non-cellular layer secreted by cells of the upper epidermis of a leaf. It waterproofs the leaf and acts as a barrier to microbes.
2 The hard, firm, external skeleton of an arthropod, which encloses its body

Cytoplasm The jelly-like substance in a cell, enclosed by the cell membrane. It contains the cell organelles and is the site of chemical reactions

Deamination The removal of the nitrogen-containing part of amino acids to form urea

Decomposer An organism that gets its energy from dead or waste organic material

Decomposition The process of rotting (decay) of dead organic material, carried out by decomposers

Denaturation The permanent effect of high temperature or extreme pH, changing the shape of the active site of an enzyme. Once denatured, an enzyme cannot catalyse a reaction

Denitrification A process carried out by denitrifying bacteria in which compounds of nitrogen are converted into gaseous nitrogen

Dentine Hard, dense, bony tissue found under the enamel of a tooth. It is softer than enamel and more yellow

Deoxygenated Blood which does not contain much oxygen

Diabetes A condition resulting from an inability to control the level of glucose in the blood, due to lack of insulin production by the pancreas

Dialysis tubing Tubing made of cellophane which has partially permeable properties. Used for experiments on osmosis

Diaphragm A sheet of tissue that separates the thorax from the abdomen. It contains muscles involved in breathing

Dichotomous key A key used to identify unfamiliar organisms. It is made up of pairs of contrasting features, starting with quite general characteristics and progressing to more specific ones

Dicotyledon A plant having two cotyledons in its seed. Dicotyledonous plants tend to have broad stalked leaves with netlike veins (e.g. strawberry, sunflower)

Diffusion The net movement of particles from a region of their higher concentration to a region of their lower concentration (i.e. down a concentration gradient), as a result of their random movement

Digestion The break-down of large, insoluble food molecules into smaller, water-soluble molecules using mechanical and chemical processes

Digestive enzyme Enzymes produced in the digestive system which break down large, insoluble food molecules into smaller, soluble ones

Diploid nucleus A nucleus containing two sets of chromosomes

Discontinuous variation A type of variation that results in a limited number of phenotypes with no intermediates. Examples include ABO blood groups, seed shape and seed colour in peas. It is caused by a gene or a small number of genes

Disease An abnormal condition of a part, organ or system of an organism resulting from various causes, for example, infection, inflammation, environmental factors or a genetic defect, and characterised by an identifiable group of signs, symptoms or both

DNA A molecule made up of two long strands coiled together to form a double helix. It contains the genetic instructions for the development and function of living things

Dominant An allele that is expressed if it is present in the genotype

Double circulation A system in which blood passes through the heart twice for each complete circuit of the body

Drug Any substance taken into the body that modifies or affects chemical reactions in the body

Duct A tube leading from a gland or an organ

Duodenum The first part of the small intestine, opening from the stomach

Ecosystem A unit containing the community of organisms and their environment, interacting together

Effector An organ which responds to a stimulus, nerve impulse or hormone

Egestion The passing out of food that has not been digested or absorbed, as faeces through the anus

Egg cell Female sex cell (gamete) involved in sexual reproduction. It contains a haploid number of chromosomes

Electrocardiogram (ECG) A trace of electrical activity associated with heartbeat. Any irregularity in the trace can be used to diagnose heart problems

Embryo The stage during which an organism develops from a fertilised egg to an independently functioning individual

Emulsify To break down fat globules in the duodenum into tiny droplets, which provides a larger surface area on which the enzyme lipase can act

Enamel Hard outer layer on the crown of a tooth

Endocrine gland A gland (also known as a ductless gland), which produces chemicals called hormones, which are released directly into the bloodstream

Endocrine system A system depending on hormones that are released into the bloodstream from endocrine glands

Enhanced greenhouse effect A gradual increase in the atmospheric temperature caused by the build-up of greenhouse gases, for example, carbon dioxide and methane

Enzymes Proteins that function as biological catalysts and are involved in all metabolic reactions

Enzyme–substrate complex A temporary combination of an enzyme molecule and the substrate molecule it acts on. The molecules join together at the enzyme's active site

Epidermis 1 The outer layer of skin of a human.
2 The layer of cells on the outside of a plant structure such as a stem or leaf

Epithelium A layer of cells in an animal, lining the inside of some organs

Eutrophication The process by which a body of water becomes enriched in dissolved nutrients (such as phosphates) that stimulate the growth of aquatic plants. It usually results in a reduction of dissolved oxygen, killing the animals living in the water

Evolution The change in the characteristics of a species over several generations, caused by slow changes in the environment. The process relies on natural selection

Excretion The removal of toxic materials and the waste products of metabolism from organisms

External intercostal muscle Muscles attached to the outside of the ribs which contract to pull the ribs upwards and outwards, to breathe in

Extinction The time when a species ceases to exist

Faeces The undigested material, plus bacteria, left in the colon after food has been digested and absorbed

Fatty acid A sub-unit of a lipid, which is released when the lipid has been digested by lipase. A lipid is made up of three fatty acid units chemically bonded to one unit of glycerol

Fermenter A large, sterile container used to grow microorganisms, for example, fungi and bacteria, on a large scale, to produce useful products such as insulin, penicillin and mycoprotein

Fertilisation The fusion of the nuclei from a male gamete (sperm) and a female gamete (egg cell)

Fetus The later stages of an animal's embryo when all the organs are present

Fibre Also known as roughage, it consists of the cellulose cell walls of plants. Humans cannot digest fibre, but it adds bulk to food being moved through the digestive system, keeping the muscles in good tone and preventing constipation

Fibrin An insoluble blood protein which forms a network of fibres across a wound, trapping red blood cells to make a blood clot

Fibrinogen A soluble protein in the blood plasma which, when a blood vessel is damaged, changes to insoluble fibrin, trapping red blood cells to form a blood clot

Filament Slender stalk which supports the anther of a flower

Flaccid The condition of a plant cell when it loses water from the vacuole

Flagellum (pl. Flagella) A long filament of cytoplasm which projects from a sperm cell. Whip-like movements of the flagellum propel the cell forwards

Follicle-stimulating hormone (FSH) A hormone secreted by the pituitary gland, which stimulates one of the follicles in an ovary to mature

Food chain Shows the transfer of energy from one organism to the next, beginning with a producer

Food supply One of the factors which can limit the growth of a population

Food web A network of interconnected food chains

Fossil fuels Fuels such as coal, natural gas and oil which have formed over millions of years from the trapped and compressed remains of dead organisms

Fovea The small area of the retina of the eye having the largest concentration of light-sensitive cells

Fruit The seed-bearing structure in flowering plants, formed from the ovary after fertilisation of a flower. Examples include apples, tomatoes and pea pods

Fungus A group of organisms made up of thread-like hyphae instead of cells. Nuclei are spread throughout the cytoplasm. They are heterotrophs (cannot make their own food) because they do not have chloroplasts

Gamete A reproductive cell. In animals, gametes are eggs and sperm. In plants they are ovules and cells contained in pollen grains

Gas exchange The exchange of oxygen and carbon dioxide, which takes place between the air and blood vessels, for example, in the lungs

Gastric secretions A liquid secreted by glands in the lining of the stomach containing the enzyme protease

Gene A length of DNA that codes for a protein

Gene mutation A random change in the base sequence of DNA

Genetically identical A term used to describe clones, which contain the same genetic information as the parent from which they were formed

Genetic modification Changing the genetic material of an organism by removing, changing or inserting individual genes

Genome The complete set of genetic information in an organism

Genotype The genetic make-up of an organism in terms of the alleles present

Genus (pl. Genera) One of the categories in classification; a group of closely related species

Germination The process by which a plant grows from a seed

Gland An organ which secretes a substance such as an enzyme or hormone

Glomerulus A coiled knot of capillaries in the cortex of the kidney involved in the filtration of blood

Glucagon A hormone secreted by the pancreas, which stimulates cells of the liver to convert stored glycogen to glucose to restore blood sugar levels when lower than normal

Glucose An example of a carbohydrate. It is a monosaccharide sugar, which is soluble and used as a substrate for respiration

Glycerol One of the functional units of lipids, released when lipid is digested by lipase

Glycogen An example of a carbohydrate. It is a polysaccharide consisting of long chains of glucose units that acts as a food storage molecule in many animal cells, for example, liver and muscle cells

Goblet cell A mucus-secreting cell found in the epithelial lining of the trachea, bronchi and some bronchioles of the respiratory tract

Gravitropism A response in which parts of a plant grow towards or away from gravity

Growth A permanent increase in size and dry mass by an increase in cell number, cell size or both

Guard cell Present in the epidermis of a leaf. Found in pairs surrounding a stoma. Involved in controlling the rate of transpiration from the leaf

Gum Fleshy covering of the jaws, through which the crown of a tooth grows

Hair erector muscles Muscles found in the dermis of the skin, responsible for raising hairs on the skin to reduce heat loss when the body is cold

Haploid nucleus A nucleus containing a single set of chromosomes

Hepatic artery The blood vessel responsible for transporting oxygenated blood to the liver

Hepatic portal vein The blood vessel responsible for transporting blood containing digested food molecules from the digestive system to the liver

Hepatic vein The blood vessel responsible for transporting blood from the liver to the vena cava

Herbicides A chemical used to kill plants that compete with crop plants

Herbivore An animal that gets its energy by eating plants

Heterozygous Having two different alleles of a particular gene

Human immunodeficiency virus (HIV) A virus transmitted by sexual contact, and also passed on through infected blood and from infected mother to her baby in the uterus, during birth or through the mother's milk. The infection can lead to acquired immune deficiency syndrome (AIDS)

Homeostasis The maintenance of a constant internal environment

Homozygous Having two identical alleles of a particular gene

Hormone A chemical substance, produced by a gland and carried by the blood, which alters the activity of one or more specific target organs

Hypothalamus A region in the brain containing a thermoregulatory centre, in which temperature receptors detect temperature changes in the blood and co-ordinate a response to them

Ileum Part of the small intestine, responsible for absorbing digested food and passing it into the bloodstream

Image size The dimensions of an image, seen through a magnifying object such as a hand lens or microscope

Immunity Defence against pathogens or disease

Implant The process by which an early embryo sinks into the lining of the uterus

Ingestion The taking of substances (e.g. food, drink) into the body through the mouth

Inheritance The transmission of genetic information from generation to generation

Insect-pollinated flowers Flowers producing small amounts of sticky pollen to be spread by insects

Insecticide A chemical used to destroy insects that eat and damage plants

Insulation Material, such as fatty tissue or raised body hairs, which reduce heat loss from an animal

Insulin A hormone secreted by the pancreas, which stimulates cells of the liver to store glucose and cells to respire faster, to restore blood sugar levels when higher than normal

Intercostal muscle Muscle attached to the ribs involved in the process of breathing

Internal intercostal muscle Muscles attached to the inside of the ribs, which contract to pull the ribs downwards and inwards to breathe out

Iodine solution A chemical reagent used to test for the presence of starch. It turns from brown to dark blue if starch is present

Ionising radiation A type of energy in the form of X-rays, radioactive compounds and ultraviolet light, which can increase the mutation rate. Exposure may lead to cancer

Iris A coloured ring of circular and radial muscle that controls the size of the pupil in the eye

Kinetic energy The energy of movement

Kingdom The highest taxonomic group used in classifying organisms. Examples include animals, plants and fungi

Lacteal The tube in the centre of a villus, into which pass the products of fat digestion in the intestine

Lactic acid A product of anaerobic respiration in muscles. Its build-up causes muscle cramps and creates oxygen debt

Lactose intolerance A digestive problem where the body does not produce enough of the enzyme lactase. Symptoms include flatulence (wind), diarrhoea and stomach pains

Larynx The voice box. It lies between the back of the mouth and the trachea

Lens A transparent, convex, flexible, jelly-like structure that refracts light to focus it onto the retina

Lignin A material found in xylem vessels, which makes the cells walls very strong and impermeable

Limiting factor Something present in the environment in such short supply that it restricts life processes

Lipase An enzyme, secreted by the pancreas, which digests fats

Lumen The inside space in a tubular structure such as an artery

Lung Gas exchange organs found inside the ribcage

Luteinising hormone (LH) A hormone secreted by the pituitary gland, which acts on a ripe follicle, stimulating maturation and release of an egg cell

Lymphocyte A type of white blood cell which makes antibodies

Magnification The observed size of an image divided by the actual size of the specimen

Maltase Enzyme that breaks down maltose to glucose

Maltose Two molecules of glucose joined together

Medulla A region of the kidney where there is reabsorption of substances the body needs, and fluid is collected for excretion

Meiosis A reduction division in which the chromosome number is halved from diploid to haploid, resulting in genetically different cells

Memory cell A type of lymphocyte which stays in the lymph nodes, reproducing swiftly if the body becomes re-infected by the same foreign organism

Meniscus The edge of a water surface that curves upwards to touch the edge of a container

Menstrual period A stage in the menstrual cycle when the uterus lining breaks down and the cells, along with blood, are passed out of the vagina

Micrometre A unit of length that is one-millionth of a metre ($1x10^{-6}$ metre)

Microvilli Microscopic projections on the surface of epithelial cells in the ileum, which increase its surface area for the absorption of digested food molecules

Millimetre A unit of length that is one-thousandth of a metre ($1x10^{-3}$ metre)

Mitochondrion (pl. Mitochondria) Tiny organelles in the cytoplasm of animal and plant cells. They are responsible for releasing energy through aerobic respiration

Mitosis Nuclear division giving rise to genetically identical cells in which the chromosome number is maintained

Monocotyledon A plant having one cotyledon in its seed. Monocotyledonous plants tend to have elongated, stalkless leaves with parallel veins (e.g. grasses and lilies)

Motor neurone A nerve cell which carries electrical impulses from the central nervous system to an effector (e.g. a muscle or a gland)

Movement An action by an organism or part of an organism causing a change of position or place

MRSA A bacterium that causes infections in different parts of the body. It can be very difficult to treat because it is resistant to some commonly used antibiotics

Mucus A slippery and stringy fluid substance which is secreted by many cells in the body to act as a lubricant, to prevent dehydration and to trap irritants like dust, smoke or bacteria

Mutation A genetic change

Natural selection The greater chance of passing on genes by the best adapted organisms

Negative feedback A reaction that causes a decrease in a function as part of the process of homeostasis

Nephron A microscopic filtering and reabsorbing structure in the kidney, made of a single glomerulus with its Bowman's capsule, renal tubule and blood capillaries

Nervous system A system of the body that coordinates its actions and sensory information by transmitting electrical signals to and from different parts of its body through a series of neurones

Neurone A nerve cell which conducts electrical impulses

Neurotransmitter molecule A chemical messenger which transmits signals across a chemical synapse from one neurone to another neurone

Nitrate A negative ion with the formula NO_{3}^{-}. It is a common component of fertilisers used to promote plant growth

Nitrification An important part of the nitrogen cycle in soil, in which ammonia is converted to nitrate by nitrifying bacteria

Nitrogen fixation An important part of the nitrogen cycle, in which nitrogen-fixing bacteria take in gaseous nitrogen and convert it to compounds of ammonia

Nucleotide A building block of DNA. It consists of a base (A, T, G or C) plus a molecule of sugar and phosphoric acid

Nucleus A structure found in the cytoplasm of most animal and plant cells containing DNA in the form of chromosomes. Its function is to control cell division, cell development and cell activities

Nutrition The taking in of materials for energy, growth and development

Oesophagus Part of the digestive system. It is a muscular tube through which food passes from the mouth to the stomach

Oestrogen A hormone, produced by the ovaries, which promotes the development and maintenance of female characteristics of the body

Optic nerve A nerve attached to the back of the eye, which transfers visual information from the retina to the brain by means of electrical impulses

Optimum The most favourable (e.g. temperature, pH)

Organ A structure made up of a group of tissues working together to perform a specific function

Organ system A group of organs with related functions working together to perform a body function

Organism An individual animal or plant, formed by all the organs and systems working together to produce an independent living thing

Osmosis The net movement of water molecules from a region of higher water potential to a region of lower water potential through a partially permeable membrane

Ovary 1 Part of the female reproductive system of mammals, where eggs are produced 2 Part of the reproductive system of a flowering plant, where ovules are produced. After fertilisation, it becomes a fruit

Oviduct A tube in female mammals which carries an egg from an ovary to the uterus, with propulsion provided by tiny cilia in the wall. Also, the site of fertilisation

Ovule Contains a haploid nucleus, which develops into a seed when fertilised

Oxidation The process whereby a compound loses an electron, or gains oxygen

Oxygen debt Also known as Excess Post-exercise Consumption (EPOC), this is a temporary shortage of oxygen in the body tissues because of vigorous exercise. Cells begin to respire anaerobically, and lactic acid builds up, which must be converted back to a harmless chemical, using oxygen in the process of aerobic respiration

Oxygenated A substance which has had oxygen added to it (e.g. blood in the lungs)

Palisade mesophyll A tissue in the leaf which is the main region for photosynthesis. Made of columnar cells which are packed with chloroplasts to trap light energy

Pancreas An organ in the abdomen which secretes pancreatic juice for the digestion of proteins, lipids and starch. Also acts as an endocrine gland, secreting the hormones insulin and glucagon

Partially permeable A structure which allows some molecules to pass through, but acts as a barrier to others, for example, cell membrane

Passive immunity Resistance to a pathogen through antibodies being passed from one individual to another, such as from mother to child

Pathogen A disease-causing organism

Penis Male sex organ which can become firm so that it can be inserted into the vagina of the female during sexual intercourse to transfer sperm

Pepsin A protein-digesting enzyme secreted in the stomach

Peripheral nervous system (PNS) Part of the nervous system, made up of nerves that lie outside of the central nervous system (CNS). Its main function is to connect the CNS to the organs, limbs and skin

Peristalsis Waves of contractions of longitudinal and circular muscles which move food through the digestive system

Permeable A structure which allows molecules or ions to pass through it. The cell wall of a plant cell is freely permeable to water and mineral ions

Petal Part of a flower. Often large and brightly coloured to attract insects

Phagocyte A white blood cell which can ingest foreign particles, for example, bacteria

Phagocytosis A process of engulfing and digesting harmful bacteria and cell debris

Phenotype The observable features of an organism

Phloem Vascular plant tissue responsible for the transport of sugars and amino acids from a source (e.g. leaf) to a sink or storage roots

Photosynthesis The process by which plants make carbohydrates from raw materials using energy from light

Phototropism A response in which parts of a plant grow towards or away from light

Physical digestion The breakdown of food into smaller pieces without chemical change to the food molecules

Placenta The organ in the uterus, formed during pregnancy, which enables nutrients, oxygen and waste materials to pass between the mother and her embryo

Plasma The liquid component of the blood. It transports substances in solution around the body

Plasmid Small circle of DNA in a bacterium. Often carries genes for antibiotic resistance. Used in genetic modification to introduce foreign DNA

Plasmolysis The partial collapse of a cell as the result of loss of water by osmosis

Platelet Special blood cells formed in the red bone marrow that help to clot the blood at wounds to stop bleeding and prevent pathogens entering the body

Pollen Contains the male sex cell of a flowering plant. The sex cell is haploid

Pollen tube A tube which grows from a pollen grain, carrying the male sex cell to the ovule

Pollination The transfer of pollen grains from an anther to a stigma

Population A group of organisms of one species, living in the same area, at the same time

Potometer Apparatus designed to measure the rate of uptake of water by a plant

Predation The act of a predator feeding on its prey

Producer An organism that makes its own organic nutrients, usually using energy from sunlight, through photosynthesis

Product A substance that is formed as the result of a chemical reaction

Progesterone The female hormone produced by the corpus luteum in the ovary after ovulation

Prokaryote Very small, single-celled organisms with a cell wall but no nucleus (e.g. bacteria)

Prostate gland A gland in the male reproductive system below the bladder which adds fluids and nutrients to sperm to form semen

Protease An enzyme, secreted by the stomach, pancreas and ileum, which digests protein

Protein A molecule containing the elements carbon, hydrogen, oxygen, nitrogen and sometimes sulfur or phosphorus. Consists of long chains of sub-units called amino acids

Protoctist Single-celled organisms with a nucleus (e.g. Amoeba). Some contain chloroplasts (e.g. Euglena)

Puberty The period of growth during which humans become sexually mature

Pulmonary artery The blood vessel which carries deoxygenated blood from the right ventricle of the heart to the lungs

Pulmonary vein The blood vessel which carries oxygenated blood from the lungs to the left atrium of the heart

Pulp Soft material inside the pulp cavity of a tooth containing nerves and blood vessels

Pulse The ripple of pressure that passes down an artery as the result of a heart beat

Punnett square A square diagram, used to predict the genotypes of a genetic cross

Pupil The hole in the centre of the iris of the eye. Its diameter can be changed by the muscles of the iris according to the brightness of light entering the eye

Pure-breeding A group of genetically identical individuals that always produce offspring of the same phenotype when bred together

Pyramid of biomass A diagram showing the amount of biomass at each trophic level in a food chain. It forms the shape of a pyramid

Pyramid of energy A diagram showing the amount of energy at each trophic level in a food chain. It forms the shape of a pyramid

Pyramid of numbers A diagram showing the number of organisms at each trophic level in a food chain

Quantitative Results you can measure

Radial muscle A muscle in the iris. When the muscle contracts, the pupil dilates, for example, in dim light

Ratio The proportion, showing one value compared to another

Receptor A sense organ which detects a stimulus

Receptor protein A protein which binds to a neurotransmitter substance in a synapse. When this happens, a new nerve impulse is generated

Recessive An allele that is only expressed when there is no dominant allele of the gene present in the genotype

Reflex action A rapid and automatic response to a stimulus

Reflex arc The nerve pathway involved in a reflex action, involving a receptor, sensory neurone, motor neurone and effector

Refract Bending, used to describe curved surfaces of the cornea and lens both bending the light rays that enter the eye

Relay neurone A nerve cell, found in the central nervous system, which passes signals from a sensory neurone to a motor neurone

Renal artery A blood vessel which carries blood from the aorta to a kidney

Renal vein A blood vessel which carries blood from a kidney to the vena cava

Reproduction The processes that make more of the same kind of organism

Resistant Used to describe bacteria which are not killed by antibiotics

Respiration The chemical reactions in all living cells that release energy from glucose

Respirometer An apparatus that can measure the rate of respiration by seeing how quickly oxygen is taken up

Retina A light-sensitive layer at the back of the eye containing light receptors, some of which are sensitive to light of different colours

Ribosome A cell organelle in the cytoplasm responsible for the synthesis of proteins from amino acids

Rickets A deficiency disease caused by a shortage of vitamin D in the diet. The symptoms are soft bones which can become deformed

Root hair A cell on the epidermis of a root with a hair-like outgrowth, increasing the surface area of the cell to absorb water and mineral ions from the soil

Root system Part of a plant below ground. Roots anchor the plant in the soil, absorb water and mineral ions for making food in the leaves and store food

Saliva A fluid, produced and secreted by salivary glands in the mouth, containing the enzyme salivary amylase

Salivary gland A gland in the mouth which produces saliva

Sap The liquid inside the large central vacuole of a plant cell. It stores materials and provides mechanical support to a plant

Scrotum A sac which holds the testes outside the body, keeping them cooler than body temperature

Scurvy A disease in which skin and blood vessels are susceptible to damage and infection due to lack of vitamin C in the diet

Secondary sexual characteristics Physical characteristics developing at puberty which distinguish between the sexes but not directly involved in reproduction

Seed A fertilised ovule containing the plant embryo

Selective breeding A process used by humans to produce varieties of animals and plants that have an increased economic importance

Self-pollination The transfer of pollen grains from the anther of a flower to the stigma of the same flower, or a different flower on the same plant

Semilunar valve Pocket-like valves in the main arteries leaving the heart which prevent the return of blood to the ventricles

Sense organ Groups of receptor cells responding to specific stimuli, such as light, sound, touch, temperature and chemicals

Sensory neurone A nerve cell that conducts impulses from a sense organ to the central nervous system

Sepal A leaf-like structure on the outside of a flower, which protects the flower while in bud

Septum A wall of muscle which separates the right and left sides of the heart

Set point The physiological value around which the normal range fluctuates

Sewage treatment The process of removing contaminants from municipal wastewater, containing mainly household sewage and some industrial wastewater

Sexual reproduction The process involving the fusion of haploid nuclei (fertilisation) to form a diploid zygote and the production of genetically different offspring

Shivering Uncontrollable bursts of rapid muscular contraction in the limbs, releasing heat to increase the body temperature

Shoot The part of a flowering plant that is visible above the ground. It consists of an upright stem with leaves and buds

Sink A part of a plant which receives sucrose translocated from the leaves

Source A part of a plant (the leaf) producing sucrose, which is moved to other parts of the plant by translocation

Specialised A structure which has developed to do one particular job

Species A group of organisms that can reproduce to produce fertile offspring

Specificity A characteristic of enzymes and antibodies in the way they only act on one substance, for example, amylase only breaks down starch

Sperm Male sex cell (gamete) involved in sexual reproduction in animals. It contains a haploid number of chromosomes

Sperm duct Muscular tube in the male reproductive system that links the testis to the urethra to allow the passage of semen containing sperm

Spongy mesophyll A tissue in the leaf made of spherical, loosely packed cells containing chloroplasts to trap light energy. Air spaces between the cells allow gas exchange

Stamen The male reproductive part of a flower, made up of the anther and filament

Starch An example of a carbohydrate. It is a polysaccharide consisting of long chains of glucose units that acts as a food storage molecule in plants

Stem cell Unspecialised cells that divide by mitosis to produce daughter cells that can become specialised for specific functions

Stigma A sticky surface at the top of the carpel of a flower that receives pollen during pollination

Stimulus An event in the surroundings or internal anatomy of an organism, which produces a reaction

Stoma (pl. Stomata) A structure, in the epidermis of a plant, which consists of a pore enclosed by two guard cells. It permits gaseous exchange with the atmosphere

Style Part of the carpel of a flower that links the stigma to the ovary. Pollen tubes grow through it

Substrate The substance on which an enzyme acts

Sucrose A disaccharide sugar produced mainly from sugar cane or sugar beet. It is moved around a plant in the process of translocation

Suspensory ligament The fibres running from the edge of the lens of the eye to the ciliary body

Sustainable resource A resource that is produced as rapidly as it is removed from the environment so that it does not run out

Sweat gland Structures in the dermis of the skin which secrete sweat to help reduce the body temperature

Sweating The process of secretion of sweat onto the surface of the skin to help reduce the body temperature

Synapse A junction between two neurones

Synaptic gap A small space in a synapse between the end of one neurone and the start of another. Neurotransmitter substances diffuse across the gap to trigger a new electrical impulse

Synthesis The production of an organic compound in a living thing, in a process catalysed by enzymes

Testis (pl. Testes) Part of the male reproductive system in animals that produces sperm

Testosterone A hormone, produced by the testes, which promotes the development and maintenance of male characteristics of the body

Tissue A group of cells with similar structures working together to perform a shared function

Toxin A poisonous protein produced, for example, by pathogenic bacteria

Trachea A cartilaginous tube that connects the larynx to the bronchi of the lungs, allowing the passage of air. Also called the windpipe

Translocation The movement of sucrose and amino acids in the phloem

Transmissible disease A disease in which the pathogen can be passed from one host to another

Transpiration The loss of water vapour from leaves

Trophic level The position of an organism in a food chain, food web, pyramid of numbers or ecological pyramid

Trypsin An enzyme that digests protein in the small intestine

Turgid The state of a cell as the result of taking in water by osmosis

Turgor pressure The pressure built up in a plant cell as a result of taking in water by osmosis

Umbilical cord A tube linking the fetus and the placenta of its mother. Nutrients and oxygen pass to the fetus; carbon dioxide, urea and other wastes pass to the mother

Urea A nitrogenous waste product, made in the liver during the break-down of excess amino acids, and excreted in urine

Ureter A tube connecting a kidney to the bladder, carrying urine

Urethra A tube leading from the bladder, carrying urine. In males it passes through the penis and also carries semen

Urine A solution of water, urea and mineral ions which is excreted by the kidneys

Uterus A muscular organ in the female reproductive system where the fetus develops

Vaccination The introduction into the body of a harmless form of a pathogen that has antigens, either by injection or swallowing. The treatment is used to give active immunity to a disease

Vaccine A preparation of dead, inactive or harmless bacteria or viruses which, when introduced to the body, cause it to produce antibodies to protect against a disease

Vacuole A fluid-filled space in a cell, surrounded by a membrane

Vagina Part of the female reproductive system which receives the male penis during sexual intercourse. Sperm are deposited in it

Variable A factor or condition that can exist in differing amounts

Variation The differences between individuals of the same species

Vascular bundle Group of specialised cells which carry water, mineral ions and food up or down the stem

Vasoconstriction The process of narrowing the diameter of an arteriole by the contraction of muscles in its walls, in order to restrict the flow of blood through the vessel to the skin. It occurs when the body is too cold

Vasodilation The process of widening the diameter of an arteriole by the relaxation of muscles in its walls, in order to allow the flow of more blood through the vessel to the skin. It occurs when the body is too hot

Vein Transport vessel in animals and plants. In animals it returns blood to the heart

Vena cava The main vein of the body, carrying blood to the heart

Ventricle A lower, more muscular chamber of the heart which receives blood from an atrium and contracts to pump blood into the arteries

Vertebrate An animal that has a backbone as part of a skeleton

Vesicle A structure in the cytoplasm of a cell which contains a liquid, for example, neurotransmitter substance in a nerve cell

Villus (pl. Villi) Small, finger-like projections that extend into the lumen of the small intestine

Virus A sub-microscopic particle which only reproduces in cells of plants and animals, causing disease

Water potential The relative tendency of water to move from one area to another by osmosis

Wilt The excessive loss of water from a plant resulting in the collapse of the leaves and stem

Xylem The tissue in the vascular bundle of a plant which transports water and mineral ions

Zygote The cell produced when a male and female sex cell fuse. It is diploid

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