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- Add notes and highlight areas
- Add double-page spreads into lesson plans

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- Download and view on any device or browser
- Add, edit and synchronise notes across two devices
- Access their personal copy on the move

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The core content of this digital textbook has been approved by AQA for use with our qualification. This means that we have checked that it broadly covers the specification and that we are satisfied with the overall quality. We have also approved the printed version of this book. We do not however check or approve any links or any functionality. Full details of our approval process can be found on our website.

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Please note that when teaching the AQA GCSE Biology course, you must refer to AQA’s specification as your definitive source of information. While this digital book has been written to match the specification, it cannot provide complete coverage of every aspect of the course.

A wide range of other useful resources can be found on the relevant subject pages of our website: www.aqa.org.uk.
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Welcome to the AQA GCSE Biology Student Book.

This book covers the Foundation and Higher-tier content for the 2016 AQA GCSE Biology specification.

The following features have been included to help you get the most from this book.

**Prior knowledge**

This is a short list of topics you should be familiar with before starting a chapter. The questions will help to test your understanding. Extra help and practice questions can be found online in our AQA GCSE Science Teaching & Learning Resources.

**KEY TERMS**

Important words and concepts are highlighted in the text and clearly explained for you in the margin.

**Practical**

These practical-based activities will help consolidate your learning and test your practical skills.

**Required practical**

AQA’s required practicals are clearly highlighted.

**TIPS**

These highlight important facts, common misconceptions and signpost you towards other relevant chapters. They also offer useful ideas for remembering difficult topics.

**Show you can...**

Complete the Show you can tasks to prove that you are confident in your understanding of each topic.

**Test yourself questions**

These short questions, found throughout each chapter, allow you to check your understanding as you progress through a topic.

**Higher-tier only**

Some material in this book is only required for students taking the Higher-tier examination. This content is clearly marked with the blue symbol seen here.

**Examples**

Examples of questions and calculations that feature full workings and sample answers.
Chapter review questions

These questions will test your understanding of the whole chapter. They are colour coded to show the level of difficulty and also include questions to test your maths and practical skills.

- Simple questions that everyone should be able to answer without difficulty.
- These are questions that all competent students should be able to handle.
- More demanding questions for the most able students.

Practice questions

You will find Practice questions at the end of every chapter. These follow the style of the different types of questions you might see in your examination and have marks allocated to each question part.

Working Scientifically

In this book, Working Scientifically skills are explored in detail in the activity at the end of each chapter. Work through these activities on your own or in groups. You will develop skills such as Dealing with data, Scientific thinking and Experimental skills.

Extension

Occasionally we have included material that isn’t in the AQA specification. You can use this for further reading and deepen your understanding of a topic. This may be especially useful for students hoping to study A Level science. This content is clearly marked with the green symbol seen here.

* AQA only approve the Student Book and Student eTextbook. The other resources referenced here have not been entered into the AQA approval process.
Acknowledgements
There are thousands of different types of cell found in millions of different species of life on Earth. These range from tiny bacteria that live on us and all around us to cells in birds that can fly over the Himalayas. Cells can be put into two broad groups: prokaryotic cells found in prokaryotic organisms (also called prokaryotes) and eukaryotic cells found in eukaryotic organisms (eukaryotes). Prokaryotic and eukaryotic cells have many features in common but also some key differences.

This chapter covers specification points 4.1.1.1 to 4.1.1.5 and is called Cell structure. It covers eukaryotic and prokaryotic cells, animal and plant cells in more detail, and microscopy.
Eukaryotes and prokaryotes

**KEY TERMS**

- **Eukaryotic cells** Describes cells that contain a nucleus.
- **Eukaryote** An organism that is made of eukaryotic cells (those that contain a nucleus).

Previous you could have learnt:
- that cells are the basic unit of living organisms
- about the functions of some cell parts
- about the similarities and differences between plant and animal cells
- about the adaptations of some unicellular organisms
- about the organisation of multicellular organisms: from cells to organisms.

Test yourself on prior knowledge
1. What are the functions of plant cell walls?
2. Describe a difference between plant and animal cells.
3. Explain why plant leaves are green.
4. Put the following into size order starting with the largest: tissues, cells, organ systems, organs.

**Eukaryotes**

All animal and plant cells are **eukaryotic**, which makes all plants and animals **eukaryotes**. Figure 1.1 shows examples of the huge diversity we can see in eukaryotic life on Earth.

You can see from Figure 1.1 that many eukaryotes are complex organisms. Organisms that are made from more than one cell are described as **multicellular**.
Prokaryotes (bacteria)

All bacterial cells are prokaryotic, which means that all bacteria are prokaryotes.

Prokaryotes:
- are single celled
- do not have a nucleus containing their genetic material (DNA)
- are smaller than eukaryotic cells
- may also have small rings of DNA called plasmids.

Individual bacterial cells are usually between 1 µm and 10 µm in length. One million micrometres (µm) make up one metre (m) and one thousand make up one millimetre (mm). This means that between 100 and 1000 bacteria will fit in a straight line in a space of 1 mm. Groups of bacterial cells are called colonies. Many, but not all, scientists think that prokaryotes evolved before eukaryotes and so are missing some cell parts that eukaryotic cells contain. These scientists think that prokaryotes first appeared about 3.5 billion years ago, which is only a billion years after the Earth’s crust formed.

![Figure 1.2 A bacterial cell as seen with a microscope (magnified ×20000) and as three- and two-dimensional diagrams.](image)

A typical bacterial cell is shown in Figure 1.2. The functions of bacterial cell components are shown in Table 1.1.

<table>
<thead>
<tr>
<th>Component</th>
<th>Structure and function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cytoplasm</td>
<td>This fluid is part of the cell inside the cell membrane. It is mainly water and it holds other components such as ribosomes. Here most of the chemical reactions in the cell happen (such as the making of proteins in ribosomes).</td>
</tr>
<tr>
<td>Cell wall</td>
<td>Like those of plants and fungi, bacterial cells have a cell wall to provide support. However, unlike plant cell walls this is not made of cellulose. The cell membrane is found on the inside surface of the cell wall.</td>
</tr>
<tr>
<td>Single DNA loop (DNA not in chromosomes)</td>
<td>DNA in prokaryotes is not arranged in complex chromosomes as in eukaryotic cells. It is not held within a nucleus.</td>
</tr>
<tr>
<td>Plasmids</td>
<td>These are small, circular sections of DNA. They provide genetic variation for bacteria.</td>
</tr>
<tr>
<td>Cell membrane</td>
<td>This controls what substances go in and out of a cell. It also has internal extensions that have enzymes attached to them. Respiration occurs in these enzymes.</td>
</tr>
<tr>
<td>Ribosome</td>
<td>Proteins are made by ribosomes, which are present in the cytoplasm.</td>
</tr>
</tbody>
</table>
Figure 1.3 shows how small bacterial cells are. Typical eukaryotic cells are much larger than this. However, even eukaryotic cells are microscopic. This means you can’t see a single cell without using a microscope.

Test yourself
1. Name the type of DNA structure only present in prokaryotes.
2. Which organisms have a single loop of DNA?
3. Describe the main difference between eukaryotic and prokaryotic cells.
4. Describe the function of ribosomes.

Show you can...
Explain why some scientists think that prokaryotic cells evolved first.

Animal and plant cells

Generalised (typical) animal cells
Plant and animal cells are eukaryotic. They can be single-celled (unicellular) or belong to multicellular organisms. Eukaryotic cells almost always have a nucleus and are generally larger than prokaryotic cells.

The structure of a generalised animal cell is shown in Figure 1.4.
Components of animal cells

In the previous section we looked at bacterial cells. Animal cells, including human cells, have many components in common with these. The cytoplasm of animal cells is also mainly water and it holds other components such as ribosomes. In the cytoplasm most of the chemical reactions in the cell happen (such as the making of proteins using ribosomes).

The cell membrane of animal cells also surrounds the cell. There are no cell walls in animal cells and so the membrane is on the outside of these cells. The membrane controls what substances go in and out of the cell. Many of your cells need glucose and oxygen for respiration, and these substances move by diffusion or are transported into the cells from the blood, where they are found at a higher concentration. Carbon dioxide moves back into the blood capillaries through the membrane.

Mitochondria are small organelles found in the cytoplasm and are only present in eukaryotic cells. They are the site of most of a cell’s respiration. Here the energy stored in glucose is released for the cell to complete the seven life processes. Without this energy all cells die. More active cells, such as those in muscles or sperm cells, usually have more mitochondria because these cells need more energy. Mitochondria have many folds inside them, which make their surface area very large to increase the rate at which energy is released.

Ribosomes are the site of protein synthesis. These organelles are present in the cytoplasm of animal cells.

Animal cells are unlike bacterial cells in that they usually possess a nucleus. This component is present in almost all eukaryotic cells. It is found in the cytoplasm and is surrounded by its own membrane. The cell’s genetic material (DNA) is enclosed within it, arranged into chromosomes. The nucleus controls the activities of the cell.

Generalised (typical) plant cells

Like animal cells, plant cells are eukaryotic. They have a nucleus and they are generally larger than prokaryotic (bacterial) cells.

![Figure 1.5 A generalised plant cell as three- and two-dimensional diagrams.](image)
Components of plant cells

Plant cells have many components in common with animal cells, including a nucleus in which the organism’s genetic material (DNA) is found. As in animal cells, the DNA is packaged into chromosomes. Plant cells also have ribosomes for protein synthesis and mitochondria for respiration in their cytoplasm.

Plant cells have some components not present in animal cells. Chloroplasts are small organelles, full of a green pigment called chlorophyll, which absorb the light necessary for photosynthesis to occur. This reaction uses the light energy from the Sun to convert carbon dioxide and water into glucose and oxygen and so provides an energy source for the plant. It is the green chlorophyll in plants that gives some of their parts their green colour. Most roots are hidden from the Sun and so cannot photosynthesise. They do not have chloroplasts and so are often white, not green.

There are huge numbers of chloroplasts in leaf cells. There are often well over half a million per square millimetre of leaf.

Plant cells also have a cell wall, unlike animal cells. This is made from cellulose and provides structure for the cell. Plants would not be able to stand upright to catch light energy from the Sun without cell walls. The cell membrane is found inside the cell wall.

Many plant cells also contain a permanent vacuole. This is filled with cell sap (water in which dissolved sugars and mineral ions are found). The pressure in the vacuole presses the cytoplasm against the wall to keep the cell turgid.

Use a light microscope to observe, draw and label a selection of plant and animal cells

In this practical you will examine the structure and features of different animal and plant cells.

Your teacher may provide you with slides showing a range of cells from plants and animals. If this is the case, use Method 1 below.

Method 1
1. Place your slide on a microscope stage and observe using the lowest power objective lens.
2. Focus in on the image and then increase the magnification until you can clearly observe the cell’s structure.
3. Make a drawing of what you observe, labelling any structures you recognise. Ensure that you record the magnification you used when making your observations.

Alternatively, your teacher may ask you to make up your own slides to examine the cells in a range of tissues. If this is the case, use Method 2 below.

Method 2

Examining plant cells
1. Wear eye protection.
2. Use tweezers to remove a thin sheet of cells (epidermal tissue) from the inner part of an onion layer.
Place this flat on a microscope slide, being careful not to fold it.

Place a drop of iodine onto the onion tissue.

Carefully lower a cover slip on top of the tissue, ensuring no air bubbles form (Figure 1.7).

Follow the steps in Method 1 above to examine and draw the cells present.

Repeat this process using a leaf from a piece of pond weed (*Elodea*), but add a drop of water rather than iodine.

**Examining animal cells**

1. Wear eye protection.
2. Using an interdental stick or flossing brush from a freshly opened pack, gently scrape the inside of your cheek.
3. Smear the cotton swab on the centre of the microscope slide in small circles.
4. Add a drop of methylene blue solution to the centre of the slide. This is an irritant and can be harmful, so avoid contact with the skin and wear eye protection.
5. Carefully lower a cover slip on top and remove any excess stain by allowing a paper towel to touch one side of the cover slip.
6. Follow the steps in Method 1 above to examine and draw the cells present.
7. Repeat this process using a single hair from your head. Place the base of the hair on a microscope slide and then stain and observe the cells using the microscope.
8. Put all slides in a solution of 1% Virkon.

**Questions**

1. Compare and contrast the structure of the cells you observed. Were any features missing from the animal cells you observed that were present in the plant cells?
2. Can you relate any of the structures or features of the cells you observed to their functions or position in the organisms they came from?
3. Order the cells you observed, from smallest to largest.

**TIP**

It is important that you can explain how the main components of animal and plant cells are linked to their structure.
The previous section looked at generalised animal and plant cells. Eukaryotic organisms like us are not usually made only of generalised cells. We have developed specialised cells that have adaptations to allow them to complete specific functions. Red blood cells, for example, have a biconcave shape (which dips in the middle on both sides) to allow oxygen to be absorbed more quickly. They also have no nucleus, which means they can absorb more oxygen. Some specialised cells in animals and plants, together with their adaptations, are listed below.

**Sperm cell**

In humans, about a teaspoon of semen is ejaculated during a male orgasm. In the semen are tens of millions of sperm cells, which must swim through the female reproductive system. Here one cell may fertilise an ovum (egg cell). Sperm cells have a tail to help them swim towards the ovum (Figure 1.8). They have a relatively large number of mitochondria to release the energy from glucose during respiration. This is needed to keep them swimming. The nucleus of a human sperm contains the genetic material (DNA) of the father. This will make up half of the DNA of the baby.

**Nerve cell**

Our nervous system controls and coordinates all our actions. These can be either voluntary actions (such as picking up the television remote control) or involuntary actions (such as our heart beating faster when we exercise). There are two main parts to our nervous system. The first is our central nervous system (CNS), which is made up of our brain and spinal cord. The other is our peripheral nervous system (PNS), which is all the other nerve cells that connect to the CNS but then spread out across our bodies. To control our actions, signals must be sent and received. Nerve impulses are electrical signals that travel along nerve cells. To keep these impulses moving quickly, some of our nerve cells are the longest cells in our body. Their long extensions are called axons and these have a myelin sheath surrounding much of their length (Figure 1.9). This acts like the plastic coating on an electrical wire and insulates the electrical impulse. The cell body of the nerve cell also has smaller extensions, which allow it to pick up signals from neighbouring cells.

**KEY TERMS**

- **Biconcave** Describes a shape with a dip that curves inwards on both sides.
- **Ova (singular ovum)** Eggs.
- **Axon** The extension of a nerve cell along which electrical impulses travel.
- **Myelin sheath** The insulating cover along an axon, which speeds up the electrical impulse.
Muscle cell

There are three types of muscle in our bodies, all of which can contract and relax. Smooth muscle contracts and relaxes automatically and is found in places such as the linings of the vessels that make up our circulatory system and the iris of our eyes. Cardiac muscle also contracts and relaxes automatically and is found in our heart. The third type is skeletal muscle, which is usually found attached to our bones. We control the contractions of this type of muscle, so its movements are not automatic.

All three types of muscle are made from muscle cells. These are specialised cells that can contract and so move parts of the body. Muscle cells contain large numbers of mitochondria, as muscular contraction requires a lot of energy.

Root hair cell

Root hair cells in plants have a small thin extension, which pokes out into the soil (Figure 1.11). Many plants have roots with such high numbers of long root hairs that they can look like a spider’s web. The purpose of these hairs is to increase the surface area of the root that is in contact with the soil. This allows the plant to absorb more water and minerals from the soil. For example, a single rye plant has billions of root hairs, which have a total length of hundreds of miles! Without these it is likely that the adult plant would not be able to absorb enough water to survive.

Xylem cell

Xylem cells form long tubes running along the roots and stems of plants. They carry water and some dissolved minerals from the roots upwards to other parts of the plant. This water evaporates and is lost from leaves as water vapour during the continual process of transpiration. Xylem cells also carry water to the green parts of plants...
for photosynthesis during the day. Xylem tubes are made from lots of individual cells that have died and have no end walls and no contents, leaving a hollow tube like a pipe (Figure 1.12). They have reinforced side walls to support the weight of the plant. The side walls are strengthened by a substance called lignin.

Movement of water up the plant

▲ Figure 1.12 The parts of a xylem tube.

Phloem cell

Phloem cells carry the glucose (as sucrose) made in photosynthesis from the leaves of a plant to all other parts of the plant in cell sap. This process is called translocation. The sugar is used immediately in respiration to release energy for the plant or is stored as starch in cells or in structures such as the roots of vegetables. Unlike xylem, phloem cells are living. They have fewer cell organelles than many other types of cell, which allows the sugar to travel easily. Rather than having no end walls (as in xylem), phloem cells have specialised end walls called sieve plates that have small holes in them (Figure 1.13).

Phloem cells are arranged with xylem cells to form bundles. These make up the veins you can see in a leaf (Figure 1.14).

Cell differentiation

The previous two sections have looked at generalised and specialised animal and plant cells. After generalised cells are formed they become specialised as an organism develops. This process is called cell differentiation. Your cells did this while you were in your mother’s uterus. Part of this process involves cells developing specific structures within them to allow them to function. For example, muscle cells need to release lots of energy during respiration and so require a high number of mitochondria. Unlike animal cells, most plant cells retain the ability to differentiate throughout their life. We would not be able to take plant cuttings without this.

KEY TERMS

Phloem Living cells that carry sugars made in photosynthesis to all cells of a plant.

Translocation The movement of sugars made in photosynthesis from the leaves of plants.

▲ Figure 1.14 The veins of a leaf are made from xylem tubes transporting water to the leaf and phloem tubes transporting sugars away from it.

TIP

You should remember that root hair cells, xylem cells and phloem cells are only found in plants.
Microscopy

The invention of the microscope is likely to have occurred in the 1590s in the Netherlands by makers of eye glasses. Seventy-five years later, in 1665, English scientist Robert Hooke (1635–1703) published a book called *Micrographia*, which was full of impressive images including a drawing of the eyes of a fly, seen using a microscope. In this book he first used the word ‘cell’, because when he looked at plant cells using his microscope he was reminded of the cells in a honeycomb.

The microscopes used by Robert Hooke looked very different from those that you may use in your science lessons today. But the thing they have in common is that they all use magnifying lenses to enlarge images.

**Light microscopes**

The parts of a light microscope and their functions are shown in Table 1.2.

<table>
<thead>
<tr>
<th>Part</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyepiece lens</td>
<td>You look through this lens to see your sample. This is often ×10.</td>
</tr>
<tr>
<td>Objective lens</td>
<td>Usually there are three to choose from (often ×5, ×10 and ×25). The smallest will be the easiest to focus, so select this first. When you have focused this lens try a different one with a greater magnification.</td>
</tr>
<tr>
<td>Stage</td>
<td>This holds the sample securely, often using two metal clips.</td>
</tr>
<tr>
<td>Specimen</td>
<td>This is usually placed in a drop of water or stain on a microscope slide under a very thin glass cover slip.</td>
</tr>
<tr>
<td>Mirror</td>
<td>This reflects the light up through the sample, and then the objective and eyepiece lenses into your eyes. In more expensive/advanced microscopes the mirror is replaced by a light source.</td>
</tr>
<tr>
<td>Course focus</td>
<td>This quickly and easily moves the stage up and down to focus on the sample.</td>
</tr>
<tr>
<td>Fine focus</td>
<td>This sensitively and slowly moves the stage up and down to allow you to make your image very sharp.</td>
</tr>
</tbody>
</table>

The total magnification of the image you are looking at is calculated by:

\[
\text{total magnification} = \frac{\text{magnification of eyepiece lens}}{\text{magnification of objective lens}}
\]

Show you can...

Explain why animals and plants have specialised cells.

Test yourself

- 8 Give the function of nerve cells.
- 9 Name the components of nerve cells.
- 10 Describe how red blood cells are adapted for their function.
- 11 Describe how root hair cells are adapted for their function.
Electron microscopes use electrons in place of rays of light to make an image (Figure 1.16). The wavelength of electrons can be up to 100 000 times smaller than that of visible light. This means that electron microscopes can take images at significantly higher magnifications. The first electron microscope was made by German scientists Ernst Ruska (1906–1988) and Max Knoll (1897–1969) in 1931. This was a transmission electron microscope (TEM). Several years later, in 1937, German scientist Manfred von Ardenne (1907–1997) invented a second type called a scanning electron microscope (SEM).

Transmission electron microscopes fire a large beam of electrons though a very thin slice of the specimen. All electrons are fired at the same time. Not all of the electrons pass though the specimen. The image is made from only those electrons that do.

Scanning electron microscopes also use a beam of electrons. This beam is much smaller and scans across the whole image but not all at the same time. Electrons scatter from the surface of the sample and are detected to make an image.

As a consequence of their different methods of working, the images that these two microscopes make are very different from each other. Images from transmission electron microscopes are flat and are usually taken in cross-section through a specimen. That is, they are frequently used to look at a section through a cell. Scanning electron microscopes don’t need thin samples so can be used to make images that look more three-dimensional. All electron microscope images are black and white. On occasions scientists colour these images to make them look more striking (Figure 1.17).

Electron microscopes can magnify much more than light microscopes, but the key thing is that they have a much greater resolution. The resolution of microscopes is the shortest distance between two parts of a specimen that can be seen as two distinctly separate points. As a result of the wavelength of light the maximum resolution of light microscopes is 200 nm. (There are one million nanometres (nm) in a millimetre.) An electron microscope can resolve points up to 2000 times closer than a light microscope, at a separation of just 0.1 nm.

Test yourself

12 What is the range of magnification you might see in a light microscope?
13 Give the resolution of an electron microscope.
14 Describe why electron microscopes have greater magnification.
15 Describe a disadvantage of using an electron microscope.

Show you can...

Explain why scanning electron microscopes can take images that look three-dimensional.
Chapter review questions

1. Name two organelles that are only present in prokaryotic cells.
2. Name the substances present in a plant cell vacuole.
3. What substances move into leaf cells?
4. Explain why plant cells are often green.
5. Describe how the structure of sperm cells helps their function.
6. Name the three types of muscle tissue.
7. Describe how you would make a microscope slide to look at an onion cell.
8. Describe the function of flagella.

9. a) These two images were taken using which types of microscope? Be specific in your answer.
   b) Suggest one advantage and one disadvantage of using an electron microscope.
10. Describe three differences between prokaryotic and eukaryotic cells.
11. Give the function of cytoplasm and what it is made from.
12. What are the function of ribosomes?
13. Describe three differences between plant and animal cells.
14. Give the function of a vacuole and in which organism’s cells it is often found.
15. Describe how a nerve cell is adapted for its function.
16. Describe how the structure of red blood cells helps their function.
17. Define the term ‘resolution’.
18. a) Name the two types of cell you can see in this photo (left, upper image).
   b) Use the scale to estimate the length of the small cell.
   c) Explain why the small cell might have relatively more mitochondria than the large cell.
19. Explain why some cells have more mitochondria than other cells.
20. Define the term ‘turgid’.
21. Explain which substances move out of animal cells.
22. Explain how xylem cells are adapted for their function.
23. How do many scientists think that prokaryotic and eukaryotic cells first evolved?
24. a) This cell (left, lower image) is 1.3 mm long. By how much has it been magnified?
   b) Explain how this cell is adapted.
Practice questions

1 Orchids are often found growing high up on other plants. They are unusual plants in that some species have green roots.
   a) Choose the name of the chemical substance that makes parts of plants green:
      A chloroplast
      B chlorophyll
      C mitochondria
      D ribosome  [1 mark]
   b) Suggest why orchids grow on other plants.  [1 mark]
   c) Suggest why some orchids have green roots.  [3 marks]
   d) Explain how root hair cells are adapted for their function.  [3 marks]

2 Life exists on Earth as single-celled or multicellular organisms. Bacteria are single-celled organisms that grow in many places.
   ▲ Figure 1.18
   a) Copy the diagram of a bacterial cell in Figure 1.18, and complete the missing labels.  [2 marks]
   b) Which of the following cell components is not found in prokaryotic organisms?
      A cell wall
      B DNA
      C nucleus
      D mitochondria  [2 marks]
   c) Name the process that keeps bacteria alive.  [1 mark]

3 Microscopes have been around since the end of the 16th century. Their invention allowed us to see single-celled organisms for the first time and also understand that multicellular organisms are made up of many cells.
   ▲ Figure 1.19
   a) Copy the diagram of a light microscope in Figure 1.19, and complete the missing labels.  [3 marks]
   b) Choose the part of the microscope that light first passes through:
      A fine focus
      B objective lens
      C eyepiece lens
      D slide  [1 mark]
   c) How is the total magnification of a light microscope calculated?  [1 mark]
   d) Describe two differences between a light microscope and an electron microscope.  [4 marks]

4 Describe the similarities and differences between prokaryotic cells and eukaryotic plant and animal cells.  [6 marks]
Microscopy and magnification

It is important that you can carry out calculations involving magnifications, real size and image size.

Magnification is a measure of how many times an object has been enlarged. If a sesame seed is actually 3 mm long, but in a diagram has been drawn to be 3 cm long, then it has been magnified 10 times. You can work out magnification using the formula:

\[
\text{magnification} = \frac{\text{image size}}{\text{actual size}}
\]

For example, this drawing of a flea is 40 mm long but the actual flea is 2 mm.

To work out the magnification the above formula is used:

\[
\text{magnification} = \frac{40 \text{ mm}}{2 \text{ mm}} = \times 20
\]

Sometimes you might want to know the actual size of an object if you know the magnification and size of the image. To work this out the formula for magnification can be rearranged:

\[
\text{actual size} = \frac{\text{image size}}{\text{magnification}}
\]

Also, you might need to work out what image size would be produced if you were given the actual size of the image and its magnification:

\[
\text{image size} = \text{actual size} \times \frac{\text{magnification}}{\text{magnification}}
\]

A formula triangle can be used to help you rearrange the equation.

TIP

It is really important to ensure that measurements are always in the same units. So if you have mixed units you will need to convert them all to the same format.
Extension

Often the actual object being studied is too small to be measured using a ruler, which means that a scale lower than a millimetre is needed. A micrometre (µm) is a thousandth of a millimetre and a millionth of a metre.

Using standard form, this can be written as:

\[
1 \mu m = 1 \times 10^{-3} \text{ mm and }
1 \mu m = 1 \times 10^{-6} \text{ m}.
\]

Questions

1. What is the magnification of this spider?
2. If a pinhead measures 1.8 mm and is magnified ×12.5, how large would the image be?
3. If an image of a snake’s fang is 22.5 cm and it has been magnified ×7.5, how large is the actual fang?
4. What is the actual size of this frog’s eye if the image has been magnified ×1.5?

TIP

Cell lengths are usually measured in µm (micrometres). Sub-cellular structures can be measured in mm or nm (nanometres), depending on their size.
Example
If the actual size of this cheek cell is 60µm, by how much has it been magnified?

- First measure the size of the cell in mm. In this micrograph, the cell is 45 mm wide.
- Then convert this to µm by multiplying by 1000.

So $45 \times 1000 = 45\,000\,\mu m$
- To work out the magnification:

\[
\text{magnification} = \frac{\text{image size}}{\text{real size}}
\]

\[
\text{magnification} = \frac{45\,000}{60}
\]

\[
\text{magnification} = \times 750
\]

Question
What is the actual size of this red blood cell if it has been magnified ×6000?
When your father’s sperm fused with your mother’s ovum you were only a single stem cell. Years later, you are now made from thousands of billions of cells. These are arranged in a very specific way and specialised into several hundred different types. This chapter explains how your body cells grew from that single fertilised ovum by a process of cell division called mitosis and how the same process replaces your damaged tissues and those cells that die naturally. This process is key to life on Earth.

This chapter covers specification points 4.1.2.1 to 4.1.2.3 and is called Cell division. It covers the structure of chromosomes, mitosis, stem cells and cell differentiation.
Chromosomes

Eukaryotic cells are those that contain a nucleus. These can either be single-celled organisms such as protozoa or single cells of larger multicellular organisms such as trees, insects and you.

Almost all of the cells in your body have a nucleus in which your genetic material (DNA) is found. Half of this came from your father carried by his sperm, and the other half came from your mother in her ovum. Sex cells (sperm and ova) are called *gametes*, and these have only half of an organism’s DNA in them. They are described as *haploid* cells. Apart from gametes and some cells such as red blood cells that have no nucleus, most of your cells contain two sets of DNA: half from your mother and half from your father. Any cell with these two copies is described as a *diploid* cell.

The DNA in any one of your body cells (not the gametes) stretches to approximately 2 metres long. Almost all the cells in your body are so small they can only be seen using a microscope. In order to fit all of this DNA into a cell this small, it is coiled into structures called chromosomes. Humans have 23 pairs of chromosomes. We say they come in pairs to remind ourselves that half were inherited from each of our parents. This means that there are 46 chromosomes in a diploid human cell. This is called the ‘chromosome number’. Other eukaryotic animals and plants have different chromosome numbers. For example, mosquitos have a chromosome number of 2. This means they have one pair of chromosomes: one from each parent.

You can see in Figure 2.1 that the 23 pairs of chromosomes present in a human body cell are numbered in order of their size, which varies considerably. Each of these chromosomes is divided into separate regions called *genes*. Each gene contains the genetic instructions to make a protein and therefore produce a characteristic. Because you have two copies of each chromosome, you also have two copies of each gene: one from your mother and one from your father. These two different versions of the same gene are called *alleles*.

Figure 2.1 also shows us that chromosomes are long, thin structures. They have a point towards the middle where they appear to pinch inwards. This is called the centromere, and no genes are present at this point.

![Figure 2.1 The 46 chromosomes present in a human body cell.](image)
Mitosis and the cell cycle

House dust is mainly made from our dead skin cells, and those of our family or pets who live with us. Our houses are always becoming dusty, which means that our skin is continually dying and falling off. But we don't run out of skin. This means that we must be continually replacing our dead skin cells as they fall off. This replacement process is carried out by a type of cell division called mitosis. This process copies a diploid body cell, which contains all of your DNA, giving two new cells identical to the original cell and each other. Without this process we would not be able to grow from a fertilised ovum, repair ourselves from damage, or replace the cells that die naturally throughout our lives.

Steps in mitosis

Figure 2.2 shows the steps in mitosis. At the top of the diagram, you can see one cell with four chromosomes. The two red ones come from one parent and the two blue ones come from the second parent. The small blue and red chromosomes make one pair, and the large blue and red chromosomes make the other pair. If this were a human cell it would have 23 pairs, but this would be too confusing in a diagram.

The first step in mitosis is for the membrane around the nucleus to disappear and all the chromosomes to shorten and fatten. This helps make the following steps easier. The chromosomes have already copied themselves completely. At this point the cells contain 46 chromosomes and 46 copies. You can see in the second box in Figure 2.2 that each of the four chromosomes now looks like an X-shape. Each of these is a chromosome with its copy.
The chromosomes and their copies then migrate to the middle of each cell, which is shown in Stage 2 in the diagram. The chromosomes and their copies split apart. The chromosomes are pulled to one side of the cell and the copies to the other. This is shown in Stage 3 in the diagram. The cell membrane then starts to pinch inwards and eventually touches the other side, and splits into two identical cells. We call these daughter cells. Each new daughter cell is an exact copy of the original cell.

Mitosis began several hours after your father’s sperm fertilised your mother’s ovum. Your body was growing very quickly at this point, so both the old cells and the copies of the cells remained. Otherwise you would always be just one cell big! As you get older, some of your cells start to die and mitosis is used to replace these cells. In this case the original cells die and the new cells remain in their place.

Mitosis is one stage in the cell cycle. This is the series of events that occurs in a cell before and during its replication. The first stage in the cell cycle is called interphase. Cells spend most of their lives in interphase. Here the cell is growing and increasing the number of subcellular structures, such as ribosomes and mitochondria. Next comes mitosis, in which the cell splits into two daughter cells. The third and final stage is called cytokinesis. Here the cell divides into two.

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Stem cells

**Stem cells in mammals**

A stem cell is a cell that can differentiate into any other type of cell. In mammals there are two types of stem cell. The first type are embryonic stem cells, and these cells were present when you were a zygote and an embryo (between 1 and 9 weeks old). They divide rapidly during mitosis and begin to differentiate within several days of the sperm fertilising the ovum. Within 21 to 22 days the human embryo has enough differentiated cells to form a beating heart.

Embryonic stem cells can grow into any specialised cell found in the adult organism. They are described as totipotent. Once an embryonic stem cell has differentiated into a specialised cell it cannot change back or turn into any other type of cell.

Adults have the second type of stem cell, which are simply called stem cells or adult stem cells (although they are also found in children). Stem cells grow only in specific parts of the body, such as bone marrow. They are used to repair the body when it is injured. Crucially they can only develop into the type of cell found in that location. So blood adult stem cells can only develop into red or white blood cells. They cannot turn into any cell in the way that embryonic stem cells can. They are described as multipotent. Scientists find these cells interesting to study, but they may not be as potentially useful as embryonic stem cells.

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Some animals have stem cells that allow them to regenerate parts of their body. For example, lizards can shed, and later regrow, their tail if seized by a predator. Other animals can go even further than this. If one leg of a starfish is severed by a predator it will grow back. If the severed leg is the portion that is left, it will grow another four legs. Starfish are often seen with one short or long leg in comparison to the others (Figure 2.6).
Stem cells and differentiation in plants

Plants also have stem cells. However, those found in plants keep their ability to specialise into any type of cell. In a plant, the stem cells are located in a region called the **meristem**. This is where much of the plant’s growth occurs. Meristems are found in shoot tips, where they encourage the shoots to grow towards the light. They are also found in the root tips, where they encourage the roots to grow downwards towards water.

The fact that plant stem cells can differentiate into other cells throughout the mature organism’s life allows us to take cuttings. Here a small section of stem, usually with a few leaves, is removed. This is often dipped into rooting powder (Figure 2.7), which contains plant **hormones** to speed up differentiation. This cutting is then placed directly into the soil. The stem cells towards the bottom of the cutting will quickly grow into root cells and grow downwards. A little later we have a genetically identical copy of the parent plant, often described as a **clone**. Although there is no **genetic variation**, because of **environmental variation**, the clone will not always look identical to the parent organism. Much of our food that comes from plants, such as crops with disease resistance, is grown from clones following this method. Many rare or valuable plants such as orchids and roses are grown in this way.

Stem cell research

Stem cell research is an **ethical issue**. This means that some people disagree with it for religious or moral reasons. Many scientists think that research into the medical uses of stem cells might help:

- treat paralysed patients by making new nerve cells to transplant into a severed spinal cord or damaged brain
- treat conditions such as diabetes to replace the cells in the body that are no longer working properly
- replace cells of the choroid in the eye to help patients see again
- replace injured or defective organs.
By using stem cells from an injured person’s own body in a process called therapeutic cloning, doctors can be sure that the cells will not be rejected in the way that some transplants are. In the future, treatments involving therapeutic cloning of stem cells might be used to treat many medical conditions.

The most useful stem cells for this research are embryonic because they are totipotent; they can develop into any type of cell. These are often collected from waste cells in left-over umbilical cord after a mother has given birth. They are found in fertilised ova that are not selected to be put into a woman’s uterus during *in vitro fertilisation (IVF)*. It is with this that some people have an ethical issue. Some believe that a fertilised ovum is a life. Some believe that a fertilised ovum has rights and that its use in medical research amounts to murder. For this reason the regulations surrounding stem cell research are extremely tight, and some countries forbid it completely. Using stem cells can have other problems too, such as causing viral infections when infected stem cells are used.

**KEY TERM**

*In vitro fertilisation (IVF)* A medical procedure in which ova are fertilised outside of a woman, then placed into her uterus to develop into a baby.

**Activity**

**Stem cell research**

Stem cell research is one of the most hotly debated areas of medical science. Since the first isolation of embryonic stem cells from mice in the 1980s, there have been great advances in understanding of stem cells and their potential uses in medicine. Alongside this there has been much controversy about the ethical implications of stem cell use, particularly those obtained from embryos.

The UK Government is funding stem cell research and wants the UK to be a world leader in such research.

**Questions**

1. Working in small groups, come up with a list of views that different members of society might have for and against stem cell research.

2. Write each reason on a sticky note or piece of paper and rank them based on which are the strongest and weakest arguments for and against stem cell research.

3. Write a letter to the Government expressing your views about stem cell research and whether you feel the Government should be funding it. Ensure you support your views with reasons. You may like to use the internet to find extra information from a range of sources to support your arguments.

**Show you can…**

Explain the benefits of stem cell research.

**Test yourself**

7. Define the term ‘stem cell’.

8. Name the two types of stem cell.

9. Describe why stem cell research is an ethical issue.

10. Describe the steps in IVF.
Chapter review questions

1. Name the two human gametes.
2. Give the collective term for sperm and ova.
3. What is the number of chromosomes in a human skin cell?
4. Name the gametes in plants.
5. How many cells are at the beginning and end of mitosis?
6. Suggest why embryonic stem cells are likely to be more useful than adult stem cells in medical research.
7. Give two examples of specialised cells in animals.
8. Where are adult stem cells found?
9. Name two animals that can regenerate.
10. Define the term ‘clone’.
11. Explain why plant cuttings are clones.
12. Give two examples of diploid human cells.

13. How many chromosomes are there in a human gamete?
14. Give the common name for ova.
15. What is the chromosome number of humans?
16. Define the term ‘gene’.
17. Define the term ‘allele’.
18. Describe the process of mitosis.
19. What is the purpose of mitosis?

20. How many cell divisions occur during mitosis?
21. Explain why gametes are haploid.
22. Describe the genetic variation in daughter cells from mitosis.
23. Define the term ‘cell differentiation’.
24. Define the term ‘totipotent’.
25. Define the term ‘multipotent’.
26. Name the region of a plant in which cell differentiation occurs.
27. Name two types of differentiated cell in plants.
28. Describe the process of taking a cutting.
29. Describe how plant hormones are used in taking cuttings.
30. Suggest why some people protest against stem cell research.
31. Define the term ‘in vitro fertilisation’.
32. Explain why chromosomes come in pairs.
33. Define the term ‘chromatid’.
34. Explain the difference between chromosomes and chromatids.
Practice questions

1 How many chromosomes are there in a human diploid cell? [1 mark]
   A 48  C 44
   B 46  D 42

2 Which of these cells are haploid? [1 mark]
   A Nerve cell
   B Epithelial cell
   C Sperm cell
   D White blood cell

3 What type of daughter cells are produced in mitosis? [1 mark]
   A Identical diploid body cells
   B Non-identical diploid gametes
   C Identical haploid body cells
   D Non-identical haploid gametes

4 Figure 2.10 shows the nucleus of a cell that is starting to divide.

   a) Name structure A. [1 mark]
   b) Draw a diagram to show the appearance of a nucleus from a cell produced by mitosis of the cell in Figure 2.10. [2 marks]

5 Figure 2.11 shows some cells in human skin.

   a) Name the type of cell division that produces new skin cells. [1 mark]
   b) Explain why it is important for skin cells to be able to divide. [1 mark]
   c) Describe what must happen to the genetic material before a skin cell can divide. [1 mark]

6 Scientists believe that stem cells could have many potential uses in medicine.
   a) Stem cells are described as being undifferentiated cells. What does this mean? [1 mark]
   b) Stem cells found in liver tissue are called adult stem cells. These cells are often used to repair the body. Suggest another source of adult stem cells other than the liver. [1 mark]
   c) Embryonic stem cells are useful in medicine. Explain why. [1 mark]
   d) Many people have differing ethical views on the use of embryonic stem cells. Suggest two reasons why some people are against the use of these cells. [2 marks]

7 Describe the main stages of mitosis in human cells. [6 marks]
Hypotheses and predictions
Humans have a total of 46 chromosomes, arranged in 23 pairs. Not all living things have this many: some have more chromosomes and some have fewer. Since the 1900s, when scientists were beginning to observe chromosomes more closely, they have hypothesised and made predictions linked to chromosome number.

Questions
1. Using the data in Table 2.1, come up with a hypothesis that explains the reason for the chromosome number in the animals given.
2. Scientists use their hypotheses to make predictions. Predict the diploid number of chromosomes in an elephant.
3. Predict the diploid number of chromosomes in a hedgehog.
4. Predict the diploid number of chromosomes in a goldfish.

Your hypothesis is probably linked to the idea that more complex organisms will have more chromosomes and maybe even that because they are larger they need more DNA (genes) to code for the greater amount of proteins they need to produce.

This is exactly what scientists originally thought, and indeed if you predicted that an elephant would have more chromosomes than a human you would be right: it has 56 diploid chromosomes. However, your hypothesis and prediction would not be supported by the data for the hedgehog, which has a total of 90 chromosomes, or a goldfish, which has 94.

As more and more organisms have had their chromosome numbers determined it has become apparent that there is no link between the complexity of organisms and chromosome number. This means that scientists have rejected their original hypothesis and are trying to come up with new ideas to explain the variations seen.

Today, scientists still don’t know the exact reason for differing chromosome numbers in organisms, but it is hypothesised that it is linked to their evolution and mutations that occurred in common ancestors.

For example, in some organisms two chromosomes can become fused together. This fusion of chromosomes is thought to explain the differences between chromosome number in humans and great apes. It is hypothesised that the ancestor of humans and apes had 48 chromosomes in 24 pairs but that in humans two of the chromosomes became fused so that we ended up with 46 chromosomes in 23 pairs, while the great apes still have 48 chromosomes in 24 pairs.

Scientists made a prediction that if two chromosomes had fused to make one, we should see similarities in the gene banding on the one human chromosome compared to those found on the two separate chromosomes.

Questions
5. What other evidence from Figure 2.12 supports this hypothesis of two chromosomes fusing?
What does smelling your best friend’s deodorant have in common with making a cup of tea? One thing is that they both involve the movement of particles. Particles spread out naturally from areas of high concentration to areas of low concentration. This movement is called diffusion and it is a key biological process. Without it your cells would not receive oxygen or glucose and so quickly die.

This chapter covers specification points 4.1.3.1 to 4.1.3.3 and is called Transport in cells.

It covers diffusion, osmosis and active transport.
Examples of diffusion

When you put your deodorant on in the morning the highest concentration is under your arm. But all of the deodorant particles don’t remain under your arm, or nobody would be able to smell them. They slowly move by diffusion (we say they diffuse) from a high concentration under your arm to the lower concentration found in the air. The same is true of tea particles when you add hot water to your teabag. The particles of tea don’t remain in the high concentration within the bag – they spread out to the lower concentration found in the boiling water.

In the body, diffusion occurs across cell membranes. A good place to study diffusion is in the lungs.
3 Transport in cells

Diffusion in the lungs

When we breathe in, we take air that is relatively high in oxygen into our lungs. When in the individual alveoli in our lungs, the air is one tiny membrane away from our blood, which has a lower concentration of oxygen than the air. So the oxygen naturally diffuses from inside the alveoli into the blood. Because the blood in our body is always moving, the blood that now has a higher concentration of oxygen is immediately moved away to the tissues and organs and is replaced by ‘new’ blood with lower levels of oxygen. This means more oxygen will always diffuse into the ‘new’ blood. Oxygen is now at a high concentration in the blood.

The reverse is also true when the blood that is now high in oxygen reaches our tissues and organs. Here it travels through the tiny capillaries and is only one membrane away from the closest cells. These cells have a low concentration of oxygen because they have just used their oxygen in respiration to release energy from glucose. So the oxygen moves from a high concentration in the blood to a lower concentration in the tissues.

Carbon dioxide diffuses in the reverse direction. It is produced during respiration in the tissues and organs and so is in a higher concentration within them. The blood moving towards the tissues and organs has a low concentration of carbon dioxide because it has just come from the lungs, where it unloaded carbon dioxide and picked up oxygen. So the carbon dioxide diffuses from a high concentration in the cells to a low concentration in the blood. The blood now has a high concentration of carbon dioxide. It is transported to the lungs, where the carbon dioxide diffuses from an area of high concentration in the blood to an area of lower concentration in the alveoli. You then breathe it out.

TIP
Many students find diffusion in the lungs a difficult idea to visualise. Perhaps turning the text into a flow diagram might help. Remember that when the blood receives oxygen in the lungs it increases its concentration from low to high.

KEY TERMS
Alveoli Tiny air sacs found in the lungs through which gases exchange between blood and air.
Capillaries Tiny blood vessels found between arteries and veins that carry blood into tissues and organs.

Figure 3.3 Diffusion of gases between an alveolus and a blood capillary in the lung.

Adaptations of the lungs

The combined surface area of your lungs is the total area that is open to air inside your lungs and to blood on the other side. Your lungs have a surface area of about half the size of a tennis court. This means they have a huge area to allow oxygen to diffuse from the alveoli into the blood and carbon dioxide to diffuse from the blood into the lungs.
In addition to having a large surface area, your lungs are adapted for effective gas exchange by:

- having moist membranes that allow substances to diffuse faster across them
- having thin linings (usually one cell layer thick)
- having a rich blood supply
- breathing (ventilation), providing a regular supply of fresh air.

Diffusion also occurs in other places in the body. Glucose is found in high concentrations in your small intestine, particularly after you have eaten a sugary meal. Here it crosses from the microscopic structures called villi into your blood, just as oxygen crosses from the alveoli in your lungs into your blood. The blood now has a high concentration of glucose and travels to your tissues and organs. These have a lower concentration of glucose because they have been using it for respiration. So the glucose diffuses from your blood into your cells.

**KEY TERMS**

**Ventilation** Breathing in (inhaling) and out (exhaling).

**Villi (singular villus)** Tiny finger-like projections that increase the surface area of the small intestine.

**TIPS**

- Some people confuse the process of breathing, called ventilation, with the release of energy from glucose in the chemical reaction called respiration.
- It is important that you can explain how the small intestine is adapted to absorb materials.

**Surface area**

Make a fist with one hand and use a piece of string and a ruler to measure around the outside of it from the base of your thumb to the base of your little finger. Now open your hand and measure from the base of your thumb around all your fingers to end in the same place. What is this a model for?

Some of your cells make urea as a waste product. This is at high concentration in your cells and a lower concentration in your blood, so it diffuses from your cells to your blood. It is transported in the blood to your kidneys for excretion.

**Diffusion in other organisms**

The size of many organisms is determined by the maximum distance that substances can diffuse quickly. Insects, for example, do not have lungs and therefore do not breathe. They simply have a number of small tubes that run into their bodies. These are called spiracles. Oxygen diffuses from these tubes into the cells of the insect because the cells are using it for respiration. So it moves from an area of higher concentration in the spiracles an area of lower concentration in the cells. The maximum size of insects is in part determined by the distance that oxygen can quickly diffuse into their cells.

These smaller organisms do have an advantage over larger ones, however. The smaller they are the greater the relative size of their surface area compared to their volume. That is, they have a greater surface area to volume ratio. This means that if their cells are roughly the same size as ours they have more surface area for oxygen to diffuse into than we have.

Large organisms like us need exchange surfaces such as alveoli and villi and a transport system such as the blood to transport substances around our bodies. This is because larger organisms have a smaller surface area to volume ratio.

Fish absorb dissolved oxygen into their blood by diffusion in their gills. These structures have a large surface area to maximise this.
Factors that affect diffusion

Concentration gradient
The steeper the concentration gradient (the bigger the difference in the number of particles between an area of high concentration and an area of lower concentration), the more likely the particles are to diffuse down the concentration gradient. For example, the more deodorant you put on, the more the particles of deodorant are likely to diffuse into the air, and so the more likely other people are to smell them.

Temperature
At higher temperatures all particles have more kinetic energy. They move faster as a consequence. This means that they are more likely to spread out from their high concentration to areas of lower concentration.

Surface area of the membrane
The larger the surface area of the membrane the more particles can diffuse at once. Many people who have smoked for long periods of time have a reduced surface area in their lungs. This is called emphysema. Because their lung surface area is reduced, they are less able to get oxygen into their blood. They therefore often find it harder to exercise.

Test yourself
1. Define the term ‘diffusion’.
2. Name the holes through which insects absorb oxygen.
3. Describe four ways in which your alveoli are adapted to their function.

Investigating surface area to volume ratio and diffusion

A class carried out an investigation to examine the effect of surface area on the diffusion of dye. They were provided with three cubes of clear agar jelly that had been cut to different sizes (Figure 3.6).

Cube A was 1 × 1 × 1 cm.
Cube B was 2 × 2 × 2 cm.
Cube C was 4 × 4 × 4 cm.

Each cube was placed in a 200 cm³ beaker and the beaker was filled with 150 cm³ of blue dye. The cubes were left in the dye for 5 minutes. After this time the cubes were removed and any excess dye washed off before drying with a paper towel.

The cubes were then cut in half and observations were made on how far the dye had moved into the agar (Figure 3.7).

Questions
1. Give two variables that were controlled in this investigation.
2. To work out the total surface area (SA) for cube A, first the surface area of one face needs to be calculated: this is 1 × 1. This then needs to be multiplied by the total number of faces (6), so the calculation is 1 × 1 × 6 = 6 cm². To work out the volume, all the dimensions should be multiplied: 1 × 1 × 1 = 1 cm³. Copy and complete Table 3.1 by working out the surface area and volumes for cubes B and C.
To make sure diffusion rates are fast enough, multicellular organisms have many adaptations to increase diffusion. Examples can be found in the lungs in humans, root hair cells and leaves in plants, and gills in fish. Gills contain many finely divided sections of tissue that are rich in blood capillaries. All the finely divided sections added together give a very large surface area.

Osmosis

We learnt in the previous section that particles of gases and liquids naturally move from areas of high concentration to areas of lower concentration by diffusion and that this can be across a membrane. Osmosis is the net diffusion of water from an area of high concentration of water to an area of lower concentration of water across a partially permeable membrane. Water is the only substance that has a special name for diffusion. As in diffusion, no additional energy is used, and so this is a passive process. Because osmosis is from a high to a lower concentration of water, we say it is down a concentration gradient.

- Example of osmosis

When it rains, water is present in a high concentration in the soil surrounding plant roots. The concentration of water inside the plant is lower, particularly if it hasn’t rained for a while. So the water moves naturally from the soil into the plant cells across the membranes of the cells by diffusion. Because this is water and it moves across a membrane to get into the cells, we call this process osmosis and we say that water is osmosing into the cells.

The water will then be carried up to the leaves, where most of it will evaporate from tiny holes called stomata. This process is called transpiration. Because water is continuously evaporating, it will continuously be ‘pulled up’ from the roots, which means that they almost always have a lower concentration of water than in the soil.
Comparing water concentrations

Scientists compare solutions of different water concentrations to see which way water will osmose. A solution of water becomes less concentrated when a greater number of other particles are in it. So very salty water has a low water concentration because of all the particles of salt. We call these diluting particles ‘solutes’.

If two solutions have the same concentration of water and solutes then there is no net overall movement of water. The same volume of water will move in both directions. We say these solutions are isotonic. Red blood cells and our blood plasma are isotonic for water. That is, they are at the same concentration. Water might osmose into or out from your red blood cells but at roughly the same volumes.

If one solution has a higher concentration of solute than another we describe the first one as hypertonic. Crucially, because this has a higher solute concentration it has a lower water concentration. So if we took a red blood cell and put it into a very salty hypertonic solution (brine), the water from inside the blood cell would osmose into the solution. It would move from an area of high water concentration (inside the cell) to an area of lower water concentration (in the brine). The red blood cell would shrivel up as a result.

The reverse is also true. If one solution has a lower concentration of solute than another, we describe the first one as hypotonic. Crucially, because this has a lower solute concentration it has a higher water concentration. So if we took a red blood cell and put it into pure water (a hypotonic solution) the water from outside the blood cell would osmose into it. It would move from an area of high water concentration (outside the cell) to an area of lower water concentration (inside the cell). The red blood cell would swell up as a result.

Test yourself

5 Define the term ‘osmosis’.
6 Name the plant cell that is adapted to allow plants to absorb water.
7 Describe one key difference between osmosis and diffusion.
8 Describe the second key difference between osmosis and diffusion.
Investigate the effect of a range of concentrations of salt or sugar solutions on the mass of plant tissue

Here is one way to investigate osmosis in potatoes but your teacher may suggest you use another method, or investigate different types of vegetables.

**Method**
1. Label six boiling tubes 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0.
2. Using the volumes given in Table 3.2 and the 1.0 M solution of salt or sugar you have been provided with, make up the following concentrations in each boiling tube.

<table>
<thead>
<tr>
<th>Concentration in M</th>
<th>Volume of 1 M salt or sugar solution in cm³</th>
<th>Volume of distilled water in cm³</th>
<th>Total volume in cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>0.2</td>
<td>5</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>0.4</td>
<td>10</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>0.6</td>
<td>15</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>0.8</td>
<td>20</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>1.0</td>
<td>25</td>
<td>0</td>
<td>25</td>
</tr>
</tbody>
</table>

3. Using a chipper or corer, remove tissue from the middle of a potato and cut it into six equal 1 cm-long pieces.
4. Pat the first tissue sample dry with a paper towel, then measure and record its starting mass in a table like the one shown below.

5. Place a 1 cm-long piece of potato in the tube labelled 0.0 M and start the stopwatch.
6. Repeat this for the other five concentrations.
7. After 30 minutes (or the time specified by your teacher), remove the potato piece from the tube and dry it gently using a paper towel.
8. Record the end mass for the potato piece.
9. Repeat for the other concentrations after each one has been in the solution for 30 minutes.

**Questions**
1. Work out the change in mass for each potato piece and record it in your table. The mass changes will be positive if the potato piece got heavier and negative if it became lighter. Ensure you have clearly indicated this.
2. Calculate the percentage mass change for each piece of potato using the equation:

\[
% \text{ change in mass} = \frac{\text{change in mass}}{\text{starting mass}} \times 100
\]

3. Now plot a graph of your data with the sugar or salt concentration on the x-axis and the percentage change in mass on the y-axis. Think carefully about how you will set up your axes to show both positive and negative values on the same graph.
4. Why did you have to pat dry the potato piece before and after each experiment?
5. Why did working out percentage change in mass give more appropriate results than simply recording the change in mass?
6. Write a conclusion for this investigation. You will need to describe the trend shown by your graph and consider how the rate of osmosis is affected by the concentration of solution.
7. Use your graph to predict what concentration of salt or sugar would have led to no change in mass in a piece of potato.

<table>
<thead>
<tr>
<th>Concentration in M</th>
<th>Starting mass in g</th>
<th>End mass in g</th>
<th>Change in mass in g</th>
<th>Change in mass in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Active transport**

On occasions organisms need to move particles from areas where they are in low concentration to areas of higher concentration across membranes. This is called active transport, and we say that the particles are moving up (or against) a concentration gradient. If this is the case, then energy must be used. This is not a passive process like diffusion and osmosis. The energy needed comes from respiration.
Examples of active transport

Mineral ions and plant roots

We learnt in the previous section that water moves from an area of high concentration in soil to a lower concentration in plant roots across a membrane and that this is called osmosis. But plants need to take up mineral ions from the soil as well. These exist in very low concentrations in the soil but in high concentrations in the plants. So we might expect the mineral ions to diffuse out from the plant roots into the soil. Because the plants need to move the mineral ions from low to high concentrations, against the concentration gradient, they need to use energy. This is an example of active transport.

▲ Figure 3.11 Active transport and osmosis in a root.

Sugars and the digestive system

Following a sugary meal you will have high concentrations of sugars in your small intestine and lower concentrations in your blood. This means that sugars will naturally diffuse into your blood. But what happens if your last meal didn’t have much sugar in it? The lining of the small intestine is able to use energy to move sugars from lower concentrations in your gut into your blood.

▲ Figure 3.12 Look carefully at the nutrient concentrations in the intestine and the blood: (a) diffusion; (b) active transport.

Show you can...

Explain where active transport occurs in a plant.

Test yourself

9 Define the term ‘active transport’.
10 Where does active transport occur in the human body?
11 Describe the key difference between diffusion and active transport in terms of the concentration gradient.
12 Explain why some plant minerals move into the soil from the plant.
Chapter review questions

1. Define the term ‘diffusion’.
2. Suggest an everyday example of diffusion of gases.
3. In which direction does oxygen diffuse in the lungs?
4. In which direction does carbon dioxide diffuse in the lungs?
5. Name the blood vessels from which oxygen diffuses into cells.
6. Give the scientific name for breathing.
7. Name the process by which oxygen moves into the blood from the lungs.
8. Define the term ‘villi’.
9. Define the term ‘excretion’.
10. Define the term ‘emphysema’.
11. Define the term ‘osmosis’.
12. Describe where and how osmosis occurs in a plant.
13. Name the tiny holes in leaves.
14. Define the term ‘active transport’.
15. Describe how you could use a can of deodorant to model diffusion.
16. Is moving up a concentration gradient going from high to lower or from low to higher concentration?
17. Give an example of diffusion in a liquid.
18. Describe two ways in which your lungs are adapted for gas exchange.
19. Describe two ways in which your small intestine is adapted for absorption of glucose.
20. Name the medical condition in which the surface area of the lungs is reduced.
21. Define the term ‘partially permeable membrane’.
22. Explain why mineral ions moving into a plant root is not an example of osmosis.
23. Explain why water moving through the soil is not an example of osmosis.
24. Describe the process of transpiration.
25. Describe what would happen to the size of a red blood cell if it were placed into a solution with the same concentration of solutes.
26. Describe what would happen to the size of a red blood cell if it were placed into a solution with a higher concentration of solutes.
27. Describe what would happen to the size of a red blood cell if it were placed into a solution with a lower concentration of solutes.
28. Describe where active transport occurs in plants.
29. Describe where active transport occurs in humans.
30. Explain why we say ‘net movement’ in our definition of diffusion.
31. Explain, in terms of diffusion, why insects are small.
32. Describe how you could use your hand and a length of string to model increasing surface area.
33. Explain how the concentration gradient affects diffusion.
34. Explain how temperature affects diffusion.
35. Explain how the surface area of the membrane affects diffusion through it.
36. Describe an experiment in which you could investigate osmosis in plants using pieces of potato.
Practice questions

1. Figure 3.13 shows an alveolus and blood capillary in the lung.

   ![Figure 3.13]

   a) During gas exchange, oxygen and carbon dioxide are exchanged between the alveolus and capillary. Which arrow (A or B) shows the net direction in which oxygen moves? [1 mark]

   b) Gases move across cell membranes by diffusion.
      i) Define the term ‘diffusion’. [2 marks]
      ii) Copy and complete the sentence using words from the box below:

      | active | passive | energetic | kinetic | oxygen | energy | carbon dioxide |
      |--------|---------|-----------|---------|--------|--------|----------------|
      Diffusion is a ____________________________ processes. This means it does not require additional _____________________________. [2 marks]

2. Figure 3.14 shows four model cells containing and surrounded by the same particles, which can move freely into and out of the cell.

   a) Which cell will have the greatest net movement of particles into it? [1 mark]

   b) i) What effect would increasing the temperature have on the rate of movement of particles? [1 mark]
      ii) Explain why this would occur. [2 marks]

   c) i) Choose a cell which will have no net movement. [1 mark]
      A Cell A  B Cell B  C Cell C  D Cell D
      ii) Explain why you have chosen this cell. [1 mark]

3. Figure 3.15 shows a plant cell before and after it was placed in distilled water for 10 minutes.

   ![Figure 3.15]

   a) Describe one way in which the cell looks different after being left in distilled water. [1 mark]

   b) i) Describe what would happen if an animal cell were placed in the distilled water. [1 mark]
      ii) Explain why this is different to the plant cell. [1 mark]

   c) i) Draw a diagram to show what the plant cell would look like if it had been placed in a concentrated salt solution. [3 marks]
      ii) Explain why the cell would look this way. [3 marks]

4. A student investigated the effect of osmosis on potato pieces. This is the method used:

   a) The student started out with three pieces of potato that each measured 2 cm in length.

   b) They then placed one piece of potato into a concentrated salt solution and one piece of potato into a dilute salt solution.

   c) They left the potato pieces for 10 minutes.

   d) They then removed the potato pieces and re-measured their length.

   Describe how this method could be improved to produce valid results. [6 marks]
Presenting data in tables
Tables are an important part of most scientific investigations and are used to record the data collected. A good scientific table should present the data in a simple, neat way that is easy to understand.

When drawing tables there are some conventions (rules) to be followed:
- The independent variable (variable that is changed) should always be recorded in the first column. The dependent variable (variable that is measured) can be recorded in the next columns, with additional columns added if repeats are taken.
- The independent variable should be organised with an increasing trend.
- If a mean is calculated, this should be in the column furthest to the right.
- Column headers must have a clear title. If quantitative data are recorded, correct SI units must be given.
- Units must be given in the headers and not rewritten in the table body.
- All data in a column must be recorded to the same unit as the header, and mixed units should not be used.
- Data should be recorded to the same number of decimal places or significant figures.

Table 3.4
<table>
<thead>
<tr>
<th>Time taken to smell the deodorant</th>
<th>Room temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 minute and 45 seconds</td>
<td>10°C</td>
</tr>
<tr>
<td>54.0 seconds</td>
<td>25°C</td>
</tr>
<tr>
<td>1 minute and 30 seconds</td>
<td>15°C</td>
</tr>
<tr>
<td>1 minute</td>
<td>20°C</td>
</tr>
<tr>
<td>42.0 seconds</td>
<td>30°C</td>
</tr>
</tbody>
</table>

Questions
1. Look at Table 3.4 and note down as many mistakes as you can see.

When this information to redraw Table 3.4 above so that it is correct.
3. Read the following instructions for an experiment examining osmosis in model cells. Draw a suitable table to record the volumes required in each beaker in order to prepare for the experiment.

Method for making up solutions
Collect five 100 cm³ beakers and label them A, B, C, D and E. In each beaker add the following amounts of a concentrated fruit squash: A 100 cm³, B 75 cm³, C 50 cm³, D 25 cm³ and none in E. Then use distilled water to bring the volume of beakers B–E up to 100 cm³. Stir the solutions to ensure they are mixed thoroughly.

Questions
4. Read through the method of the experiment on the next page and design a suitable table to record the results of the experiment. Ensure you identify the independent and dependent variables.
**Method**

Take five equal-sized pieces of Visking tubing that have been soaked in water. Tie one end of each securely. Using a pipette add 10 cm\(^3\) of the solution from beaker A into one piece of Visking tubing. Tie the other end of the tubing using string and ensure that no liquid can escape. Repeat this process for the other four solutions B–E. Use a balance to determine the starting mass of each tube.

Place each tube in a separate beaker containing 200 cm\(^3\) of distilled water. After 5 minutes remove the tubes and pat dry with a paper towel. Record the mass of each tube. Return to the beakers they came from and repeat, recording the mass at 10, 15 and 20 minutes.

▲ **Figure 3.16** The liquid in the beaker is pure water. The red liquid is a very concentrated sugar solution with some red food dye added and is placed inside Visking tubing. This special tubing allows molecules of water through it but not larger sugar molecules. Water moves by osmosis through the Visking tubing from an area of high water concentration in the beaker to an area of lower water concentration (because of the added sugar) in the Visking tubing. This makes the red solution rise up the glass tube.
Animal tissues, organs and organ systems

Have you ever thought of yourself as a complicated tube with your mouth at one end and your anus at the other? This is one way you could look at your digestive system, which breaks down food into pieces that can be absorbed into your body and used by it. Your circulatory system transports this food, and other crucial substances such as oxygen, in the blood. This is only possible because a muscular organ called the heart is able to pump the blood around the body, through more than 50 thousand miles of blood vessels!

This chapter covers specification points 4.2.1.1 to 4.2.2.7 and is called Animal tissues, organs and organ systems. It covers the principles of organisation, the human digestive system and its enzymes, the heart and vessels, blood, related health issues, the effects of lifestyle, and cancer.
Levels of organisation in living organisms

In multicellular organisms, there are a number of levels of organisation. For example, in animals there are:

- **cells**: the basic building blocks of all living organisms
- **tissues**: groups of cells with similar structure and functions
- **organs**: groups of tissues that perform a specific function
- **organ systems**: organs are organized into organ systems
- **organisms**: the different organ systems make up organisms.

Table 4.1 gives some examples of these terms.

Table 4.1 Examples of levels of organisation.

<table>
<thead>
<tr>
<th>Organisational level</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell</td>
<td>Nerve cell, muscle cell</td>
</tr>
<tr>
<td>Tissue</td>
<td>Nervous tissue, skin</td>
</tr>
<tr>
<td>Organ</td>
<td>Brain, heart</td>
</tr>
<tr>
<td>Organ system</td>
<td>Nervous system, digestive system</td>
</tr>
<tr>
<td>Organism</td>
<td>Human, frog</td>
</tr>
</tbody>
</table>

The human digestive system

You eat large lumps of **insoluble** food. The breakdown products of this food must be transported around your body to reach the cells in which they are needed to complete life processes such as respiration. For this reaction alone each of your cells needs glucose (which comes from your food) and oxygen (which comes from your lungs). Digestion is the breakdown of food into smaller **soluble** pieces that can diffuse into your blood. The digestive system is the organ system that is responsible for doing this.
The human digestive system

Functions of the parts of the digestive system

Salivary glands
Your salivary glands are found in your mouth and they make saliva, particularly when you are hungry and sense food. Saliva acts as a lubricant, making it easier to swallow food. It also contains an enzyme called amylase, which is an example of a carbohydrase enzyme as it breaks down starch (a carbohydrate) into simple sugars (glucose). When food mixes with saliva in your mouth the chemical breakdown (digestion) begins.

Oesophagus
Your mouth is connected to your stomach by a thin tube approximately 20 cm long. The only function of this tube, which is called the oesophagus, is to move food quickly and easily to your stomach. The saliva helps with this. The oesophagus is sometimes called the ‘food tube’ or ‘gullet’.

Stomach
The stomach is a small organ found between the oesophagus and the small intestine. It releases a type of enzyme called protease. This starts the chemical breakdown of protein. The stomach also releases acid. This has a pH of about 2 to 3. Stomach acid does not break down food. Instead it reduces the pH of the stomach to the optimum (best) level for protease enzymes to work properly. It also is part of our first line of defence against infection, as it destroys any pathogens that may have entered the body with food or water.

The length of time that food stays in the stomach depends on the food and the person eating it. It usually takes about 6 to 8 hours for food to pass through your stomach and small intestine.
4 Animal tissues, organs and organ systems

**KEY TERMS**

**Bile** A green-coloured liquid produced by your liver, stored by your gall bladder and released into your small intestine to help break down fats.

**Lipids** Fats or oils, which are insoluble in water.

---

**TIP**

The digestive system is an example of an organ system in which several organs work together to digest and absorb food.

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**Liver**

The liver is a large organ found to the right of your stomach. It produces a green liquid called **bile**, which helps to break down fats. Bile is not an enzyme. After being made in the liver, bile is stored in the gall bladder before being released into the small intestine.

Food does not actually pass into the liver. It moves from the stomach to the small intestine.

**Gall bladder**

The gall bladder is a small organ about the size of your middle finger and the width of your big toe. Bile is stored here. As with the liver, food does not pass through the gall bladder.

**Pancreas**

The pancreas is an organ that produces the three types of enzyme found in the digestive system: carbohydride enzymes, which break down carbohydrates; protease enzymes, which break down proteins; and lipase enzymes, which break down **lipids** (fats). The pancreas releases these into the top section of the small intestine, in an area called the duodenum, close to where the gall bladder releases bile.

As with the liver and the gall bladder, food does not actually pass into the pancreas. It moves from the stomach to the small intestine.

**Small intestine**

Despite its name, the small intestine is actually the longest single part of the digestive system. It is called the small intestine because it is narrower than the large intestine. It is about 7 m long and is responsible for absorbing the products of digestion into the blood. They are then transported around the body in the blood to where they are needed.

**Villi**

Villi are microscopic finger-like projections of the lining of your small intestine. In an area about the size of your thumbnail you will have about 4000 villi. They massively increase the surface area of the small intestine and allow much more digested food to be absorbed into your blood. Each tiny villus contains blood capillaries, providing a rich blood supply to move digested food molecules to other parts of your body.

**Peristalsis**

The walls of the digestive system have rings of muscle around them and all along their length. These contract to squash lumps of food called boluses along your digestive system. Peristalsis is the rhythmic contraction of this muscle behind a bolus to push it along. This happens in the oesophagus and the small intestine.

**Large intestine**

Food that enters the large intestine is mainly indigestible fibre and water. The large intestine is wider than the small intestine but also
much shorter, at a length of about 1.5 metres long. The large intestine is responsible for absorbing water and salts from the remaining digested food.

**Figure 4.6** A view looking down a patient's large intestine.

▲ Figure 4.5 The rhythmical relaxation and contraction of the muscles lining much of the digestive system is called peristalsis.

### KEY TERM

**Defecation** Removing solid waste from the body.

### TIP

Infections of the large intestine can mean that water is not absorbed properly, resulting in too much liquid in the faeces. This is diarrhoea.

### Anus

The anus is the opening at the end of your digestive system. This controls when you go to the toilet to remove solid waste (called faeces). This process is called **defecation**.

**Show you can...**

Explain how food moves through the digestive system from mouth to anus.

### Test yourself

1. What is the length of an adult small intestine?
2. What is stored in the gall bladder?
3. Describe the process of peristalsis in the small intestine.
4. Describe how villi are adapted.

### Human digestive enzymes

We have seen that there are three types of digestive enzyme, which each act upon a different food group. The molecules that enzymes act upon are called **substrates** and the molecules that are produced are called **products**.

Table 4.1 The three types of enzyme found in the digestive system, the food groups they act upon and the molecules they are digested into.

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Substrate</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrase</td>
<td>Carbohydrate</td>
<td>Sugars</td>
</tr>
<tr>
<td>Protease</td>
<td>Proteins</td>
<td>Amino acids</td>
</tr>
<tr>
<td>Lipase</td>
<td>Lipids (fats and oils)</td>
<td>Fatty acids (three molecules) and glycerol (one molecule)</td>
</tr>
</tbody>
</table>
Bile and lipase enzymes

As we have already seen, bile is produced by the liver and stored in the gall bladder before being released into the small intestine. It is not an enzyme but does help break down large globules of fat into tiny droplets. Any substance that does this is called an emulsifier, and the process is called emulsification. Bile does not actually break down the fat itself – instead it increases the surface area of the fat for the lipase enzymes to make their digestion into fatty acids and glycerol much quicker.

Bile is alkaline and so also neutralises hydrochloric acid entering the small intestine from the stomach. This increases the pH back towards neutral for the enzymes in the small intestine to work at their optimum.
Use qualitative reagents to test for a range of carbohydrates, lipids and proteins

In this practical you will carry out practical tests to identify starch, sugars, lipids and proteins.

Your teacher will provide you with five samples labelled A–E. You need to determine which is a starch solution, which is a glucose solution, which is a protein solution, which is a lipid oil and which is water.

Copy the table below and use to collect your results:

Table 3.1

<table>
<thead>
<tr>
<th>Tube</th>
<th>Observation with starch test</th>
<th>Starch present?</th>
<th>Observation with Benedict’s test</th>
<th>Glucose present?</th>
<th>Observation with biuret test</th>
<th>Protein present?</th>
<th>Observation with emulsification test</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Use eye protection throughout the experiment.

Testing for starch: method
1. Using a pipette, add two drops of solution A into a well of a spotting tile.
2. Add two drops of iodine solution to this and record the colour observed.
3. Repeat this for the other four solutions.
4. If starch is present, a blue-black colour will be produced. Use your results to determine which tube contained starch.

Testing for glucose: method
1. Add 1 cm$^3$ of solution A to a boiling tube.
2. Add 10 drops or 1 cm$^3$ of Benedict’s reagent to this.
3. Place in a hot water bath (around 80 °C) and leave for 5 minutes.
4. Record the colour observed in your table.
5. Repeat this for the other four solutions.
6. If glucose is present, a brick-red precipitate will form. If it is not present, the solution will remain the blue of the Benedict’s reagent. Use your results to determine which tube contained glucose.

Testing for protein: method
1. Add 2 cm$^3$ of solution A to a test tube.
2. Add 2 cm$^3$ of biuret solution to this.
3. Record the colour change in your table.
4. Repeat this for the other four solutions.
5. If protein is present, the solution will turn a light lilac purple colour. If it is not present, the solution will be a cloudy blue. Use your results to determine which tube contained protein.

Testing for oil lipids: method
1. Half fill a test tube with water.
2. Add one drop of solution A to this.
3. Move the test tube from side to side to mix thoroughly.
4. Place your thumb over the top of the test tube and shake.
5. Repeat this for the other four solutions.
6. As oils do not dissolve in water, an emulsion will form. This will make the water go cloudy if lipids are present.
Questions
1 Which of your tubes contained water?
2 What are the negative results for each test?
3 Explain why food tests such as these can be considered subjective.
4 Produce a poster or pamphlet explaining how to do each food test and the positive results to expect.

The lock and key hypothesis
A hypothesis is a proposed explanation for scientific observations. The lock and key hypothesis explains how enzymes are specific for the substrates, just like a key is specific for the lock it fits. In the previous section you learnt that carbohydrase enzymes break down carbohydrate substrates and don’t digest fats, for example. The lock and key hypothesis is a model that explains why.

Digestive enzymes are specific to the substrates they help break down because of their shape. Enzymes are proteins and all the proteins found in the body have a very specific shape to help them function. A part of each enzyme is called its active site. This is the part that the substrate fits into. Any change in shape of an active site means that the breakdown will occur more slowly, or not at all. The enzyme and the substrate collide and become attached at the active site. The digestive enzyme then breaks the bonds holding the substrate together. Finally, the digestive enzyme releases the broken-down substrate.

Denaturing of enzymes
Enzymes work at an optimum temperature and pH. This is simply the temperature and pH at which they are most effective. Here we would say they have the highest enzyme activity. This is when the largest number of successful collisions takes place between the enzyme’s active site and the substrate molecules. Any movement away from these optimum conditions will reduce the effectiveness of the reaction and so lower the enzyme activity. Enzymes are denatured by high temperatures and extremes of pH. However, at low temperatures enzyme activity falls because of the lower kinetic energy, and if re-warmed the enzyme would start to work again. When denatured, enzymes are permanently damaged and won’t work anymore. The lock and key hypothesis can be used to explain this as well. When an enzyme is denatured, the shape of the active site has been altered so that it will no longer fit the substrate. In other words, the ‘key’ will no longer fit the ‘lock’.

TIPS
It doesn’t matter whether you describe the enzyme as the key and the substrate as the lock or the other way around, as long as you are consistent.
Avoid saying that enzymes have been ‘killed’. Use the term ‘denatured’ instead.
Investigate the effect of pH on the rate of reaction of amylase enzyme

In this practical you will examine how pH affects the digestion of starch by amylase.

**Method**

1. Add 10 cm³ of a 4% starch solution to a boiling tube.
2. To the same boiling tube add 10 drops of iodine solution and stir using a glass rod.
3. In a separate test tube, add 2 cm³ of a 2% amylase solution.
4. To the test tube containing the amylase, add 5 cm³ of the first buffer solution to be tested.
5. Leave both tubes in a water bath at 35 °C for 2 minutes.
6. While you are waiting, take a spotting tile and add one drop of iodine solution to each well.
7. After 2 minutes, add the amylase and buffer solution from the test tube to the starch solution in the boiling tube, and stir. **Ensure you keep the mixture of starch, buffer and amylase in the water bath throughout the experiment.**
8. Using the glass rod, remove one drop of the solution every 30 seconds and place it into a well on the spotting tile. Your teacher will tell you how many times to repeat this. Wipe clean the rod before placing it back in the solution each time.
9. Record whether or not a positive result for starch is shown.
10. Repeat the experiment using the different pH buffers provided.

**Questions**

1. Why did you need to leave the tubes in the water bath for 2 minutes before starting the experiment?
2. Plot a graph of your data with pH on the x-axis and rate of amylase activity on the y-axis.
3. Use your graph to determine the optimum pH for amylase to work at.
4. Explain how the activity of amylase changed with increasing pH.
5. Suggest improvements to the practical method that could increase the accuracy of the results.

**TIPS**

- You could make a flicker-book of the lock and key hypothesis and denaturing to help you remember how they work.
- The term ‘chemical scissors’ is often used for enzymes, but this suggests that enzymes only break down substrates. As you know, they can join substrates too.

**Digestive (breakdown) and synthesis enzymes**

So far you have learnt about the enzymes that are present in your digestive system. Digestive enzymes are those that break down (or digest) substances. Other enzymes, called synthesis enzymes, do the opposite (they help your body make complex molecules from simpler substances). An example of this is the enzyme found in protein synthesis. This joins amino acids to make proteins. Enzymes also build up absorbed sugars into carbohydrates in the body and glycerol and fatty acids into fats.
The perfect pH

An experiment was carried out to measure the effect of pH on the activity of pepsin (a protease enzyme).

10 cm³ of a 1% pepsin solution was mixed with 10 cm³ of a buffer solution at a pH of 2, 4, 6, 8 and 10. Each enzyme buffer solution was left for 5 minutes and then poured into the top of a measuring cylinder filled with set gelatine with a steel ball-bearing resting on top. The experiment was left for 24 hours and then observations were made on how deep the ball-bearing had sunk into the gelatine. As gelatine is a protein, the protease will break it down. The more active the protease enzyme is, the more the ball-bearing will sink down.

The results are shown in Table 4.2.

Table 4.2 The depth a ball-bearing reached when a pepsin solution at different pHs was added.

<table>
<thead>
<tr>
<th>pH</th>
<th>Depth ball-bearing reached in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repeat 1</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

Questions
1 Calculate the mean depth the ball-bearing reached for each pH.
2 Plot a line graph of the mean data for each pH and add range bars to show the spread of the data.
3 Use your graph and the data in Table 4.2 to identify any anomalous results.
4 Use your data to draw a conclusion about which pH is optimal for protease and using your knowledge of enzymes explain why its activity changes.
The heart and blood vessels

Many substances need to be moved around your body. For example, for respiration, you need oxygen and glucose to be taken to all your cells. You need the waste products of this reaction, carbon dioxide and water, to be removed. Other substances such as hormones are also needed in specific organs at specific times. All of these substances travel in the blood pumped through blood vessels by the heart. Transport is the function of your circulatory system. It is composed of:

- the heart, which pumps the blood around the body
- blood, which carries the blood cells and key molecules around your body
- arteries, which carry blood from your heart
- veins, which carry blood back to your heart
- capillaries, which join arteries and veins through tissues and organs.

The heart and double circulation

The heart is a pump, which is responsible for pushing blood around your body. It is an organ made from muscle and nerve tissue. The muscle does the contracting and relaxing to push the blood around and the nerve tissue passes along electrical impulses to make sure the contractions happen correctly. The heart makes its own electrical impulses, which travel along its nervous tissue and cause the contractions. These electrical impulses are generated in the ‘pacemaker’ section, which is a small bunch of cells in the wall of the top right chamber (the right atrium). The pacemaker controls the rate of your heartbeat.
There are four chambers in your heart. The top two chambers are called the left and right atria (singular atrium). These collect the blood as it returns from your body. The bottom two chambers are called the left and right ventricles. The blood is pumped from the atria into the ventricles and then from the ventricles to the rest of the body. The blood on the left and right sides of the heart never mixes. So the blood goes through the heart twice on every circulation, which takes about 1 minute when at rest. This is called ‘double circulation’.

**KEY TERMS**

**Atrium** (plural atria) An upper chamber of the heart surrounded by a thin wall of muscle.

**Ventricle** A lower chamber of the heart surrounded by a thicker wall of muscle.

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**Blood flow through the heart**

Blood returns from the lungs and is collected in the left atrium. Because it has come from the lungs it is high in oxygen and low in carbon dioxide. When the heart contracts, this blood is pumped into the left ventricle. Here it is pumped a second time when the heart next contracts and goes to the rest of the body. This pushes blood high in oxygen to all the tissues and organs that need it. The blood then is taken back to the right atrium by the vena cava. Because it has been to the tissues and organs it now has low oxygen and high carbon dioxide levels. It enters the right ventricle and then is pumped to the lungs. Here diffusion removes the carbon dioxide and replenishes the oxygen. The blood then returns to where it began, the left atrium.
There are valves at the top of the atria (the base of the arteries) to stop blood being pumped backwards and to force it into the ventricles. There are also valves between the atria and ventricles to stop blood being pumped backwards into the atria when the ventricles contract.

If you look closely at the diagrams and photograph of the heart in this chapter you will see that the walls of the left ventricle are thicker than in the right ventricle. This is because the left ventricle needs to pump the blood further to the extremities of your body, whereas the right ventricle only needs to pump it to the lungs, which are much closer.

**The blood vessels**

There are three types of blood vessel. Arteries move blood from the heart, veins take it back to the heart and capillaries carry it within tissues and organs.

**Arteries**

Arteries must cope with the blood under high pressure, as it has just been pumped from the ventricles. Because of this they have thick walls made from elastic and muscle tissue. This allows them to stretch. You can feel the surges of blood moving along your main arteries when you feel your pulse. You can do this in your wrist and neck, where arteries are particularly near the body surface.

The main artery coming from the left side of the heart, taking blood to the tissues and organs, is called the aorta. The main artery coming from the right side of the heart, taking blood to the lungs, is called the pulmonary artery. This is the only artery to carry deoxygenated blood.

**Veins**

Veins carry blood back to the heart at low pressure. This pressure has been lost as the blood travels through the arteries and capillaries. Veins also have to carry blood back to the heart against gravity from the lower parts of your body. Veins are wider than arteries but have much thinner walls. They have one-way valves to keep blood flowing in the correct direction. These are not present in arteries.

**TIPS**

- It is important that you can explain how the structure of blood vessels relates to their function.
- Turn the text about blood flow through the heart into a flow diagram to help you remember this process. Choose a point to start from (e.g. the left atrium) and always revise the flow from this point.
- You do not need to know the names of the valves.
- When you move your arm, can you hear your biceps and triceps contracting and relaxing? Of course you can’t. So why can you hear a heartbeat? It is the snapping shut of the valves in your heart that makes the characteristic ‘lub dub’ sound.

**KEY TERM**

**Deoxygenated** Without oxygen.
Blood looks red because it is the liquid that carries red blood cells and other cells and substances around your body. These include the products of your digestive system: glucose, amino acids, fatty acids and glycerol. These also include the gases oxygen and carbon dioxide from your lungs. Other molecules, including hormones and waste products, are also carried in your blood.

**Capillaries**

Capillaries are tiny blood vessels that spread out like the roots of a plant through your tissues and organs (including the heart muscle). You have billions and billions of these. They are extremely thin to allow as much oxygen as possible to diffuse from the blood into the cells and as much carbon dioxide as possible to diffuse the opposite way.

**Blood plasma** passes through capillary walls into the tissues (carrying oxygen and glucose with it), where it is called tissue fluid. This bathes the cells and helps provide them with the oxygen, glucose and other molecules they need. Waste products such as carbon dioxide pass into the tissue fluid and then into the blood.

**Figure 4.20 Exchange between the blood and tissue cells in a capillary network.**

**KEY TERM**

**Blood plasma** The straw-coloured liquid that carries our blood cells and dissolved molecules.

**Test yourself**

9 In which direction does blood flow in arteries?
10 Name the two types of chamber in the heart.
11 Describe how veins are adapted for their function.
12 Describe why the left side of the heart is bigger than the right side.

**Show you can...**

Explain how blood moves around your body from the left ventricle.

**TIP**

Because animal cells do not have a cell wall you must avoid saying that the walls of capillaries are one cell thick.

**TIP**

Blood is never blue, even if some books show it as being this colour in diagrams. It sometimes looks blue when the walls of vessels are looked at through your skin. If blood is oxygenated it is bright red and if not it is a darker red.
Blood

Figure 4.23 Haemoglobin transports oxygen from the lungs to other organs as oxyhaemoglobin in the blood.

Components of blood

Red blood cells

The red blood cells are what give our blood its red colour. In a cubic centimetre of blood there are approximately five thousand million red blood cells.

Red blood cells contain a substance called haemoglobin. This binds with the oxygen that diffuses into your blood in the alveoli. When it is carrying oxygen, it is called oxyhaemoglobin, and it turns the colour of the red blood cells from dark red to a brighter red. These red blood cells then move through arteries and capillaries to the organs and tissues that need the oxygen. Here oxygen diffuses from the red blood cell in a reverse of the reaction in the lungs. Red blood cells are adapted for carrying oxygen in many ways. Their biconcave shape gives a high surface area to volume ratio, and having no nucleus means there is more room for haemoglobin.

KEY TERMS

Haemoglobin The protein in red blood cells that can temporarily bind with oxygen to carry it around your body.

Oxyhaemoglobin The name given to the substance formed when haemoglobin in your red blood cells temporarily binds with oxygen.

White blood cells

White blood cells are part of your immune system, and they fight off invading pathogens (disease-causing microorganisms, such as bacteria). In a cubic centimetre of blood there are approximately 7.5 million white blood cells. Unlike red blood cells, white blood cells have a nucleus. There are two types of white blood cell. Phagocytes engulf pathogens and use enzymes to break them down. Lymphocytes produce antibodies to help clump pathogens together for phagocytes to destroy.

KEY TERMS

Phagocyte A type of white blood cell that engulfs pathogens.

Lymphocyte A type of white blood cell that produces antibodies to help clump pathogens together to make them easier to destroy.

Antibody A protein produced by lymphocytes that recognises pathogens and helps to clump them together.

TIP

It is important that you can recognise images of different blood cells and explain how they are adapted to their function.
Platelets

Platelets are cell fragments. In a cubic centimetre of blood there are approximately 350 million platelets. They are small structures that join together to form a scab when you cut yourself. Shortly after your skin is cut platelets start the clotting process. They do this by releasing chemicals called clotting factors. These turn a chemical called fibrinogen, which is found in your blood plasma, into fibrin. This forms a mesh and acts as a glue to help stick platelets together to form a scab.

**Blood plasma**

Plasma is a straw-coloured liquid that red and white blood cells and platelets are suspended in. It makes up about 55% of your blood and in turn is made from over 92% water. You have about 3 litres of blood plasma in the 5 litres of total blood. Many molecules that your cells need, such as glucose and amino acids, and those that are waste, such as carbon dioxide and urea, dissolve in your plasma.

**KEY TERMS**

**Coronary arteries** Arteries that supply the heart muscle with oxygenated blood.

**Atherosclerosis** A medical condition resulting from an unhealthy lifestyle that reduces the flexibility of arteries.

**Cholesterol** An important biological molecule for cell membranes but leads to atherosclerosis if found in high levels in the blood.

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**Coronary heart disease: a non-communicable disease**

The heart is a large muscle that contracts to push blood through the blood vessels all around your body. But the muscle (and nerve) cells that make up the heart organ need to respire themselves to keep on contracting and relaxing. In order to do this they must be supplied with oxygenated blood. This comes through the coronary arteries. Glucose and oxygen diffuse from the blood in these arteries and their capillaries into the cells of the heart.

An unhealthy lifestyle can cause a build-up of fatty material in the coronary arteries and a reduction in the flexibility of the artery lining (atherosclerosis). This is caused by high blood pressure, smoking and drinking excessive amounts of alcohol. Two other factors are cholesterol and poor diet. These fatty deposits slow or stop the oxygenated blood reaching the cells of the heart. This can cause cells to die and eventually lead to a heart attack.
Coronary heart disease: a non-communicable disease

In recent years coronary heart disease has become one of the major causes of death in the world. The traditional treatment for this was a heart bypass operation, in which a small section of artery is moved from another part of the patient’s body to short circuit the blockage in the coronary artery. Now more patients are being treated by using less invasive stents. These are small devices made from mesh that are inserted into the arteries to keep them open. This operation is less dangerous and faster to recover from than a heart bypass.

Eating a balanced diet, stopping (or not starting) smoking, reducing alcohol intake, maintaining a healthy weight and regular exercise all reduce the risk of coronary heart disease. Drugs such as statins are also prescribed by doctors to reduce blood cholesterol, which in turn reduces the risk of coronary heart disease.

Faulty valves

The heart has four valves inside it to stop blood flowing backwards. Any flow of blood backwards reduces the efficiency at which blood flows around the body. This means that fewer glucose, oxygen and other molecules reach the cells that need them.

Valves that are faulty might not open properly or not close completely to stop backflow. This may cause breathlessness, tiredness, dizziness and chest pain for the patient. The most common form of treatment for severe cases is replacement of the valves during open-heart surgery. These valves can be replaced by valves from donors (biological) or artificial mechanical valves.

Other heart problems

Heart contractions are controlled by a bundle of cells called the pacemaker in the lining of the right atrium. These send electrical impulses down the heart’s nerve cells to regulate the contractions. Some people are born with or develop problems with these cells, which affect the timing of the electrical impulses. An artificial pacemaker can be fitted to take over the generation of electrical impulses.

A small number of babies are born with a ‘hole in the heart’. This is a small gap between the two sides of the heart, which means that deoxygenated blood in the right side can mix with oxygenated blood in the left. This also reduces the amount of glucose, oxygen and other molecules that reach the cells that need them. The small hole is repaired during an operation.

Transplants

Heart failure is when a person’s heart stops beating. If this happens, or is likely to happen, a person usually requires a heart or heart-and-lungs transplant. These are the most serious of all operations described in this section. As with all transplants, a match between the donor and the patient must be found to stop the transplant being rejected by the patient’s immune system. Often patients are on long waiting lists until a suitable donor is found.
Health is defined as the state of physical and mental wellbeing. So being healthy means you are mentally as well as physically fit. Both physical and mental health can be maintained or improved by:

- a well-balanced diet
- regular exercise
- reducing stress
- seeking medical help for mental or physical difficulties.

A well-balanced diet will provide you with key nutrients, which in turn help you strengthen your muscles, bones, tendons and lower your chances of developing some types of cancer.

**Well-balanced diet**

A well-balanced diet means that you have the correct amount of the key food groups. This is often shown in a food pyramid, as shown in Figure 4.30. Vegetables are low in fat, high in fibre and provide your body with key vitamins. Fruits have more natural sugar in than vegetables, but are also low in fat, and high in fibre and vitamins. Fats should only be consumed in lower quantities and are found in fish and nuts as well as many processed foods. Dairy products include milk, yoghurt and cheese. These are high in protein and some vitamins but also fats and cholesterol. Recent research suggests that these negative effects of dairy
outweigh the benefits such as strengthening bones. Meat and beans are a good source of protein as well as vitamins and minerals. Some scientists think that the food pyramid is an oversimplification, whilst others think that it is a useful guide for the public.

- **Regular exercise**

The National Health Service (NHS) in the UK recommends that young people (aged 5 to 18) undertake at least 1 hour of physical activity every day. Some of this should be moderate intensity such as cycling and playground activities. Other activity should be vigorous, such as fast running and tennis. On 3 days a week this should involve muscle-strengthening exercise such as push-ups and bone-strengthening activities such as running. Exercise also improves the effectiveness of your circulatory system.

- **Physical and mental ill health**

Diseases can cause ill health. These can be communicable (catching) or those that develop without being caught. Some different types of disease can interact to cause health problems. Problems with a person’s immune system might mean they are more likely to suffer from communicable diseases. A small number of virus infections can lead to the development of cancer. The reactions of a person’s immune system to infection from a pathogen can trigger allergies such as skin rashes and asthma. Severe physical ill health can lead to mental ill health, such as stress, anxiety and depression.

Stress is the feeling of being under too much mental or emotional pressure. This can affect how you feel, think and behave. It is common for people who are stressed to sleep badly, lose their appetite and have difficulties concentrating. Anxiety is a feeling of unease, which might be worry or fear. This can be mild or severe depending upon the situation and the person. Depression affects different people in many different ways. Some people feel sad or hopeless, others lose interest in things they used to enjoy. Depression can also affect your physical health. It can make you feel tired and also lose your appetite. Severe depression can make people feel suicidal. People who feel stressed, anxious or depressed should speak to their doctor as soon as possible.

**Show you can...**

- Name the two types of wellbeing that make up health.
- What should you do if you are worried about your health?
- Describe the ways in which you can improve your physical or mental health.
- Explain why you should eat a balanced diet.
Cancer

Sometimes cell differentiation or division goes wrong and cancerous cells are produced. These cells can divide rapidly by mitosis and quickly cause a lump or tumour. This rapid growth of cells is called uncontrolled cell division. There are two types of tumour. The first is described as malignant and causes cancer. These tumours divide rapidly and grow out of control. They can spread from one part of the body to another. If this happens it is called metastasis and forms a secondary cancer. Prompt medical treatment is often needed to remove a malignant tumour or destroy the individual cells to stop the cancer spreading. The second type of tumour is described as benign and is medically less serious. Benign tumours are not cancerous, do not spread to other parts of the body and are usually contained within a membrane. They are often removed like malignant tumours, however. One in two people born after 1960 will suffer from cancer at some point in their life.

Signs of cancer include a lump formed by the tumour, unexplained bleeding, a long-term cough and a loss of weight without dieting. There are, however, over 200 different cancers in humans, and so there are many other symptoms not described here. The most important advice for anyone who thinks they might have cancer is to seek professional medical help as soon as they possibly can.

● Screening

When doctors look for cancer it is called screening. This can be feeling a bump to see if it is a tumour, and taking blood tests, urine tests or X-ray images. Doctors can also use monoclonal antibodies. Screening can also be undertaken before a person develops any symptoms, if they have a family history of developing cancer, for example.

Women have two regular types of screening for cancer. The first is the use of an X-ray machine to check for breast cancer. This is called a mammogram. These are offered automatically by the NHS to women in the UK between the ages of 50 and 70. The second is often called the smear test and looks for cervical cancer. Cells are collected from the cervix and examined under a microscope to look for abnormalities. Smear tests are offered by the NHS in the UK to women every 2 years from 25 to 49 years old, every 5 years between 50 and 64 and less frequently after that.

● Causes of cancer

More than 20% of cancers are caused by smoking, and too much alcohol can also lead to cancer. Cancers can also be caused by infections such as hepatitis B and C, and the human papillomavirus (HPV). Cancer can also occur as a result of genetic disorders inherited from parents. Other factors such as ionising radiation (including the Sun’s ultraviolet rays) and environmental pollutants from industry are other causes. Obesity is a lifestyle factor that can contribute to cancer. The risk of cancer also increases as we age.

HPV is a group of over 100 viruses that can affect your skin and moist linings in your body (in your cervix, anus, mouth and throat). It is quite
The effect of lifestyle on some non-communicable diseases

A common group of viruses and over three-quarters of all sexually active women will have HPV at some point. A small number of these viruses can lead to cervical cancer, while others cause genital warts, skin warts and verrucas. For the last few years all girls in secondary schools in the UK aged 12–13 have been offered a vaccination against HPV.

The most common cancers in the UK are breast cancer, lung cancer, prostate cancer (men only) and bowel (large intestine) cancer. It is very important to begin treatment of cancers as soon as possible. Sadly many cancers that are detected late become life-threatening. It is likely that some of these could have been treated if they were detected earlier.

Treating and preventing cancer

The two most common methods of treating cancer are chemotherapy and radiotherapy. Chemotherapy uses very powerful drugs to kill cancer cells. Radiotherapy uses X-rays to do the same thing. These stop the cancerous cells spreading. These treatments can cure a person from cancer or be used to relieve the symptoms of a person with terminal cancer (who is going to die). This last form of care is called palliative. Both chemotherapy and radiotherapy cannot differentiate cancer cells from the other healthy cells around the tumour, so they can kill other nearby cells too. Common side effects are feeling tired and weak, being sick and losing your hair.

Many cancers can be prevented from developing by leading a healthy lifestyle. This includes not smoking, not becoming over or underweight, not drinking too much alcohol, and eating healthily, including fresh fruit and vegetables.

Show you can...

Explain the different types of treatment for cancer and describe their side effects.

Test yourself

25 What are the most common cancer types in the UK?
26 Name a cancer that can only occur in men and another that can only occur in women.
27 Describe the difference between malignant and benign tumours.
28 Describe how cancers can be prevented.

The effect of lifestyle on some non-communicable diseases

The risk of coronary heart disease increases with high blood pressure, smoking and excessive alcohol, high cholesterol and poor diet. Any aspects of your lifestyle or any substances found in your body or environment that are linked to the development of a disease are called risk factors. Some risk factors are proved to cause diseases (causation), while others are only linked to a higher chance of developing them (correlation). Examples of risk factors and their associated diseases are shown in Table 4.3.
Many diseases are caused by the interaction of a number of factors. For example, people who smoke and drink excessive amounts of alcohol are more likely to be unfit and put on weight.

### Table 4.3 Risk factors, diseases and their effects.

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Disease</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obesity and lack of exercise</td>
<td>Type 2 diabetes</td>
<td>Body cells do not respond to the hormone insulin, which helps control the glucose level in the blood.</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Liver function</td>
<td>Long-term alcohol use causes liver cirrhosis. The cells in the liver stop working and are replaced by scar tissue. This stops the liver from removing toxins, storing glucose as glycogen and making bile.</td>
</tr>
<tr>
<td>Alcohol</td>
<td>Brain function</td>
<td>Excessive use of alcohol can also alter the chemicals in the brain (neurotransmitters), which pass messages between nerve cells. This can cause anxiety and depression and reduced brain function.</td>
</tr>
<tr>
<td>Smoking</td>
<td>Lung disease and cancer</td>
<td>Smoking can cause cancer in many parts of the body, including the lungs, mouth, nose, throat, liver and blood. It also increases the chances of having asthma, bronchitis and emphysema.</td>
</tr>
<tr>
<td>Smoking and alcohol</td>
<td>Underdevelopment of unborn babies</td>
<td>Alcohol and chemicals from cigarettes in the mother’s blood pass through the placenta to her baby. Without a fully developed liver the baby cannot detoxify these as well as the mother can. This can lead to miscarriage, premature birth, low birth weight and reduced brain function.</td>
</tr>
<tr>
<td>Carcinogens and ionising radiation</td>
<td>Cancer</td>
<td>Chemicals and radiation that cause cancer are called carcinogens. Tar in cigarettes, asbestos, ultraviolet from sunlight and X-rays are examples.</td>
</tr>
</tbody>
</table>

### Test yourself

29 Name the disease caused by carcinogens.
30 Name the two organs most likely to be damaged by long-term alcohol abuse.
31 Describe the effects of type 2 diabetes.

### Show you can...

Explain the difference between causation and correlation, giving an example in your answer.
Chapter review questions

1. Describe the function of saliva.
2. Where is bile stored?
3. Name the types of enzyme produced in the pancreas.
4. Give the function of the large intestine.
5. Name the organ that pumps your blood.
6. In what direction do arteries carry blood?
7. Explain why the term ‘double pump’ is used for the heart in mammals.
8. Explain why malignant tumours are more serious than benign ones.
9. Describe the side effects of radiotherapy and chemotherapy.
10. Explain why doctors often use stents rather than transplants.

11. Explain why we must digest our food.
12. Define the term ‘enzyme’.
13. Name the enzyme that breaks down proteins, and the products.
14. Name the enzyme that breaks down carbohydrates, and the products.
15. Name the enzyme that breaks down fats, and the products.
16. Describe how you could use boiled and unboiled amylase to show that enzymes denature.
17. What are the two conditions that can denature an enzyme?
18. Define the term ‘optimum’ in relation to the pH of an enzyme.
19. Describe the pathway of the blood from the left atrium.
20. Describe how capillaries are adapted for their function.
21. Describe how phagocytes protect us from pathogens.
22. Name the blood vessels that provide the heart cells with glucose and oxygen.
23. Describe the effects of having faulty heart valves.
24. Describe how doctors screen for cancer.
25. What does ‘HPV’ stand for, and what is the significance of this infection?
26. Describe the symptoms of stress.
27. Define the term ‘anxiety’.

28. Describe how you could model peristalsis using a ball and a pair of tights.
29. Explain the process of peristalsis.
30. Explain how the lock and key hypothesis models enzyme action.
31. Name the part of an enzyme that is specific to the substrate.
32. Explain denaturing of enzymes using the lock and key hypothesis.
33. Suggest the effects of having a reduced platelet count.
34. Describe the causes of atherosclerosis.
35. Explain why doctors prefer to use stents than complete bypass operations.
Practice questions

1. Figure 4.34 below shows the main organs in the human digestive system.

\[\text{\textbf{A Figure 4.34}}\]

a) Name the following organs:
   i) organ A \[1\text{ mark}\]
   ii) organ B \[1\text{ mark}\]

b) Organ C is the large intestine. What is its role? \[1\text{ mark}\]

c) Figure 4.35 shows several villi. Villi are found within the digestive system.

\[\text{\textbf{A Figure 4.35}}\]

i) In which organ would you expect to find the most villi? \[1\text{ mark}\]

   A Organ A   C Organ C
   B Organ B   D Organ D

ii) From Figure 4.35, show one way the villus is adapted to maximise the absorption of the products of digestion. \[2\text{ marks}\]

d) i) Give the term used to describe how food is moved through a digestive system. \[1\text{ mark}\]

   ii) Explain how this movement is brought about. \[2\text{ marks}\]

2. Which of the following would be the least invasive method of treatment for coronary heart disease? \[1\text{ mark}\]

   A Stent   C Pacemaker
   B Bypass   D Transplant

3. Figure 4.36 shows amylase speeding up the breakdown (digestion) of a large molecule.

\[\text{\textbf{A Figure 4.36}}\]

a) Why do large molecules need to be digested? \[1\text{ mark}\]

b) What is region X on Figure 4.36? \[1\text{ mark}\]

4. Figure 4.37 below shows three types of blood vessel.

\[\text{\textbf{A Figure 4.37}}\]

a) Name the three blood vessels. \[3\text{ marks}\]

b) Explain how the build-up of fatty material in the blood vessels that supply the heart can lead to a heart attack. \[2\text{ marks}\]

c) Copy and complete Table 4.4 to show which part of blood fits the different descriptions listed. Choose your answers from the box. \[4\text{ marks}\]

<table>
<thead>
<tr>
<th>Description</th>
<th>Part of blood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contain a substance called haemoglobin, which binds with oxygen</td>
<td>Red blood cells</td>
</tr>
<tr>
<td>Fight off invading pathogens</td>
<td></td>
</tr>
<tr>
<td>Small structures that can join together to prevent blood loss</td>
<td></td>
</tr>
<tr>
<td>Carries many molecules such as glucose and amino acids and carbon dioxide</td>
<td></td>
</tr>
<tr>
<td>Have a shape designed to maximise their surface area</td>
<td></td>
</tr>
</tbody>
</table>

5. A student carried out food tests to look for the presence of glucose, starch and protein. Describe how they would have carried out the food tests.

You should include:

a) what reagents you would use \[6\text{ marks}\]

b) what positive results would look like.
Understanding and evaluating models

The word ‘model’ is used a lot in science but what does it actually mean? Take a minute to try and define your understanding of the term ‘model’ and note down as many models you can think of that you have encountered in your science lessons.

Scientific models can take many forms, but their main purpose is to represent a process or feature in a way that is easier to predict, understand, visualise or test. Some models are scaled-up versions of real things, such as the model of DNA or a model cell. Others are scaled down, like the model of the solar system. Other models are much more abstract, explaining phenomena we can’t see and simplifying the details of them, such as the particle model. Although models are designed to help us understand by simplifying versions of reality, they can also be misleading.

As you have seen, the lock and key hypothesis is a model used to explain how enzymes work. This is shown in Figure 4.38.

Questions
1. What are the strengths of this model in representing how enzymes work?
2. What are the weaknesses of this model?
3. What does the model fail to explain or represent about enzymes?
Visking tubing is a membrane that has small holes in it. These holes are large enough to allow small molecules such as water and glucose to pass through but are too small to allow larger molecules such as starch to pass through. We can use this model to demonstrate how large molecules are digested into smaller molecules, which can leave the digestive system and enter the blood.

\[\text{beaker 1}\]

- Visking tubing containing 5 cm\(^3\) of starch solution and 1 cm\(^3\) of amylase solution
- Water
- Visking tubing containing 5 cm\(^3\) of starch solution

\[\text{beaker 2}\]

\[\text{Figure 4.39} \text{ An experiment to model the digestive system.}\]

**Questions**

4. What does the Visking tubing, and the water surrounding it, represent in this model?

5. Explain why at the start of the experiment no glucose is present inside the Visking tubing or in the water in either beaker, but over time glucose is detected in the tubing and the water in beaker 1.

6. Explain why starch was only found inside the Visking tubing and not in the water.

7. What features of the digestive system does this model not represent appropriately?

Using Plasticine or other modelling materials, create models to show the key differences between the different types of blood vessel. Ensure you can explain how each blood vessel is adapted to carry out its function.

**Questions**

8. Evaluate your models and identify three strengths and three weaknesses.
Plants are truly amazing. Without them and other photosynthesising species it is possible that the only life on Earth would be a few organisms surrounding volcanic vents on the bottom of the ocean. Plants support almost all life on Earth including you and me. Plants have far more in common with us than you might think. Like us, they are complex organisms that are arranged into tissues, organs and systems. And they are highly adapted to live and reproduce in their natural environment, just like us.

This chapter covers specification points 4.2.3.1 and 4.2.3.2 and is called Plant tissues, organs and organ systems.

It covers the structure and organisation of plant tissues, and transportation in plants.
Plant tissues

- **Epidermal tissue**
  The epidermis is a tissue made up of single layer of cells that forms the outer layer of a plant. It has many functions, including protecting against water loss, regulating the gases that are exchanged between the plant and the air (especially in the leaves), and water and mineral uptake (especially in the roots). The epidermis is usually transparent, possessing fewer green chloroplasts in its cells than other plant tissues. Being transparent, light can pass through it and reach the palisade mesophyll.

- **Palisade mesophyll**
  Immediately below the epidermis of plant leaves is the palisade mesophyll tissue. The cells in this tissue are often more tightly packed and have a more regular shape than the cells in the spongy mesophyll tissue below them. Palisade mesophyll cells have more chloroplasts than all other plant cells and so are the major site of photosynthesis.

- **Spongy mesophyll**
  Spongy mesophyll tissue is found below the palisade mesophyll tissue towards the lower surface of plant leaves. The cells in this tissue are more spherical in shape than palisade mesophyll cells and have many spaces between them. Gases enter leaves through tiny pores called stomata (singular, stoma; see Figure 5.1), which have guard cells around them. These cells control the size of the opening. More stomata are found on the underside of leaves closer to the spongy mesophyll cells. Spongy mesophyll cells have a large surface area in contact with the air spaces in the leaf to maximise gas exchange.

**Previously you could have learnt:**
- about the hierarchical organisation of multicellular organisms
- that plants make carbohydrates in their leaves by photosynthesis and gain mineral nutrients and water from the soil via their roots
- about the role of leaf stomata in gas exchange in plants
- about reproduction in plants
- about the adaptations of leaves for photosynthesis.

**Test yourself on prior knowledge**
1. Where do plants absorb water and carbon dioxide?
2. Describe the role of stomata in gas exchange.
3. Explain how leaves are adapted for photosynthesis.

**KEY TERMS**
- **Epidermis** The outermost layer of cells of a plant.
- **Palisade mesophyll** Tissue found towards the upper surface of leaves with lots of chloroplasts for photosynthesis.
- **Spongy mesophyll** Tissue found towards the bottom surface of leaves with spaces between them to allow gases to diffuse.

▲ Figure 5.1 Pores in stomata become smaller if a plant needs to reduce the amount of water being lost by transpiration.
Observing stomata on leaves

Stomata are the pores in a leaf that allow gas exchange with the atmosphere, which is required for photosynthesis and respiration. The numbers and arrangement of stomata vary on the upper and lower surfaces of plants and between plant species.

Method
1. Select the plant you want to study and use a small paintbrush to coat a small section of the upper and lower epidermis of a leaf with a water-based varnish or nail polish.
2. Leave the varnish to dry fully.
3. Using tweezers and sticky tape remove the varnish impressions from the leaves and mount each onto a labelled slide.
4. Observe the stomata using a microscope.
5. Draw and label a sketch of a stoma and the surrounding guard cells.

Questions
1. On which side of the leaf was there a higher density of stomata? Suggest why this is the case.
2. Explain how you would expect the stomata to look in a plant that is wilted compared with one that has been recently watered.

Xylem and phloem

Water flows up through xylem tissue from the roots to the leaves during transpiration. Phloem cells carry the glucose (in the form of sucrose) made in photosynthesis from the leaves of a plant to all other parts of the plant during translocation. Xylem and phloem tissues are often found together in vascular bundles.

TIP
It is important that you can explain how the structure of xylem and phloem are adapted to their functions.

Meristem

The meristem is the region of plant tissue in which stem cells are produced and so where much of the plant’s growth occurs. They are found in shoot tips reaching for the sunlight and root tips following gravity downwards.
5 Plant tissues, organs and organ systems

Plant organs

- **Root**

Roots are plant organs that are usually found below the soil. As a result they are white because they don’t contain green chloroplasts for photosynthesis. Roots absorb water by osmosis and minerals by active transport from the soil. They also anchor the plant into the soil. In addition, in some plants, roots can store the glucose made during photosynthesis, usually as starch.

The meristem is found at the very tip of the root. Here new cells are produced to allow the root to grow deeper into the soil. On the outside of roots are root hair cells to absorb water by osmosis. These are specialised epidermal cells. In the middle of the root are the xylem and phloem tissues.

![Figure 5.5 Look how many root hairs are on this one tiny root.](image)

- **Shoot**

Scientists define a shoot as the stem, its leaves, and its buds (not just the very tip of a young plant).
The meristem is found at the very tip of the shoot. Here new cells are produced to allow the shoot to grow towards the light. On the outside of shoots are epidermal cells.

**Leaf**

The leaf is a plant organ and the major site of photosynthesis. It also controls the flow of water through the plant. Previously you learnt that water is absorbed by osmosis from the soil into the roots. It is then ‘pulled’ through the plant by the transpiration stream because it is continuously being released from the leaves through stomata, which open and close to regulate this process.

**Plant organ systems**

**Transportation organ system**

You have already learnt that xylem and phloem are tissues, and that roots, shoots and leaves are plant organs. These combine to make the plant transportation organ system, which transports all substances around a plant.

**Test yourself**

4 Name the process by which water is absorbed into the roots.
5 What are the two functions of roots?
6 Where are meristems of shoots found?
7 Describe why roots are often white.

**Transpiration and the transpiration stream**

Water enters root hair cells in plant roots by osmosis. It then travels by osmosis through the cells of the root and then enters xylem cells. It travels up through the root and stem in long continuous columns of xylem cells. Eventually the xylem branches to form veins that carry the water to the leaves, where it enters the leaf cells.
Much of this water evaporates out of the leaf cells (mainly the spongy mesophyll cells) and enters the leaf air spaces as water vapour. This then diffuses out of the leaf through the air spaces and stomata. This is a continuous process, and the loss of water from a plant through the leaves is called transpiration. The constant evaporation of water from the leaves pulls, or ‘sucks’, the water up through the rest of the plant in a long, unbroken transpiration stream.

Transpiration has a number of functions, including:

- providing water for leaf cells and other cells (e.g. to keep them turgid)
- providing water to cells for the process of photosynthesis
- transporting minerals to the leaves.

Diffusion of any substance happens faster if the concentration gradient is greater (that is, the difference between the high and low concentrations is bigger). If the air surrounding a leaf is very humid (like just before a thunderstorm) then the gradient will be less steep so the rate of transpiration will be lower. On windy days the air surrounding the leaves is continually replaced. This keeps the concentration gradient steep and the rate of transpiration high. When temperatures are higher the rate of evaporation of water is higher and so transpiration occurs more rapidly. Water is also used up more rapidly during the daylight hours as some of it is used to make glucose by photosynthesis, so transpiration is increased. Also, the stomata are more likely to be open during the day.

In summary, high rates of transpiration are achieved when:

- there is more wind
- there is a high temperature
- the air is less humid
- the light intensity is high (during the day).

**Translocation**

Phloem tissue is also part of the transport organ system. Phloem transports dissolved sugars that are made in the leaves by photosynthesis to the rest of the plant. The transported sugar is usually either immediately used in respiration or stored as starch. The movement of dissolved food through the phloem is called translocation.
Investigating transpiration

A class were investigating water loss from plants and wanted to compare the amount of water lost from the upper and lower surfaces of a leaf. Four leaves of similar sizes were selected from a bush and their surface areas estimated by drawing around them on squared paper.

A thin layer of petroleum jelly was used to cover the stalks of the leaves and applied to the epidermises of some of the leaves, as shown in Table 5.1. The leaves were weighed and their starting mass recorded. They were then each hung on a piece of string using a paper clip attached to the stalk and left undisturbed in the light on a windowsill in the classroom. After an hour the leaves were re-weighed.

Table 5.1

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Estimated surface area in cm²</th>
<th>Starting mass in g</th>
<th>End mass in g</th>
<th>Change in mass in g</th>
</tr>
</thead>
<tbody>
<tr>
<td>A No petroleum jelly</td>
<td>50</td>
<td>1.34</td>
<td>1.14</td>
<td></td>
</tr>
<tr>
<td>B Petroleum jelly on the upper surface</td>
<td>55</td>
<td>1.46</td>
<td>1.38</td>
<td></td>
</tr>
<tr>
<td>C Petroleum jelly on the lower surface</td>
<td>52</td>
<td>1.42</td>
<td>1.38</td>
<td></td>
</tr>
<tr>
<td>D Petroleum jelly on both sides</td>
<td>1.56</td>
<td>1.55</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Questions
1. Copy and complete Table 5.1 by estimating the surface area of leaf D, below.
2. Determine the change in mass for each leaf.
3. Give an explanation for the class’s results.
4. Calculate the water loss for leaf A in g per cm².
5. What was the independent variable in this experiment?
6. What was the dependent variable?
7. What is a variable that should have been controlled in this experiment but was not?

Figure 5.7 Measuring the area of leaf D using squared paper.

Show you can...

Describe the conditions in which transpiration increases.

Test yourself

9. Name the plant organ from which water evaporates.
10. Name a plant organ system.
11. Describe the diffusion of oxygen from plant leaves.
Chapter review questions

1. Describe where in a leaf the spongy mesophyll layer is found.
2. Describe an adaptation of the palisade mesophyll cells.
3. Name the tissue in which water moves up a plant from its roots.
4. Explain why most roots are white.
5. Describe two functions of roots.
6. Name the tissue in a plant that produces stem cells.
7. Name the process by which plants absorb mineral ions from the soil.
8. Give an example of a plant organ.
9. Name the type of cell in which most chloroplasts are found.
10. Name the organs that make up the plant transportation organ system.
11. Name the process by which water enters a plant root.
12. Describe the difference in structure of palisade mesophyll and spongy mesophyll tissues.
13. Describe the location and function of guard cells.
14. Describe an experiment in which you could use nail varnish to investigate the number of stomata on different plant leaves.
15. Name two tissues involved in transportation in a plant.
16. Suggest where you might find a plant with green roots.
17. Define the term ‘runner’.
18. Describe the process of transpiration.
19. Define the term ‘osmosis’.
20. What is the function of the epidermis in the leaves?
21. What is the function of the epidermis in the roots?
22. Explain why more stomata are found on the lower surface of leaves.
23. What are shoots missing that more mature parts of the stem may have?
24. Explain when you might expect all the stomata of a plant to be open.
25. Explain why plants must continuously allow water to evaporate from their leaves.
26. Explain how increasing humidity affects the rate of transpiration.
27. Explain how decreasing temperature affects the rate of transpiration.
28. Suggest when during the day transpiration is most likely to be highest.
29. Explain why more transpiration happens on a windy day.
30. Describe an experiment in which you could use petroleum jelly to investigate transpiration in leaves.
Practice questions

1 Figure 5.8 shows a cross-section part of a leaf.

A

B

C

▲ Figure 5.8

a) Copy and complete Table 5.2 by identifying tissues A–C. [4 marks]

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Letter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spongy mesophyll</td>
<td></td>
</tr>
<tr>
<td>Epidermis</td>
<td></td>
</tr>
<tr>
<td>Palisade mesophyll</td>
<td></td>
</tr>
</tbody>
</table>

b) Two other tissues found in plants are xylem and phloem. These are often found together in bundles and have an important role in transporting substances around plants. Name something that is transported by:

i) the xylem [1 mark]

ii) the phloem. [1 mark]

2 Figure 5.9 shows the arrangement of stomata on the underside of the leaves of two species of plant. Each square is 0.02 mm².

A

B

▲ Figure 5.9

a) i) Name cell X. [1 mark]

ii) What is the role of cell X? [1 mark]

b) Do you think species A or B is adapted to live in a drier habitat? Explain your reason. [2 marks]

c) Suggest another adaptation that the leaves might have to help them survive in a dry habitat. [1 mark]

d) Calculate the number of stomata per 1 mm² of leaf epidermis for species B. Show your working. [2 marks]

3 Figure 5.10 shows an experiment involving water loss in plants.

▲ Figure 5.10

a) Flasks A and B were weighed and shown to have the same mass at the start of the experiment. After 10 minutes they were re-weighed. Suggest what you would expect the mass of flask A to be compared to that of flask B at the end of the experiment. [1 mark]

b) Why was flask B needed? [1 mark]

c) Suggest why cotton wool was placed in each flask. [1 mark]

d) What is the name of the process by which leaves lose water vapour? [1 mark]

A) Transportation

B) Transformation

C) Translocation

D) Transpiration

[e) Describe how this process occurs in a plant. [3 marks]

f) In which of these conditions would water loss from a plant be greatest? [1 mark]

A) Hot and humid conditions

B) Cold and humid conditions

C) Hot and dry conditions

D) Cold and dry conditions
Understanding error

There are often differences in the results obtained in an experiment caused by different types of error. A random error is usually caused by a mistake being made by the person carrying out the experiment, a change in the measuring instrument or a change in the environment that was not controlled. Random errors cause the result to vary in an unpredictable way, spreading around the true value. We can reduce the effect of random error by carrying out more repeats and calculating a mean.

A systematic error causes the readings to differ from the true value by a consistent amount each time a measurement is made. These types of error usually come from the measuring instrument, either because it is incorrectly calibrated or because it is being used incorrectly by the experimenter. Systematic errors cannot be dealt with by more readings; instead the whole data collection needs to be repeated using a different technique or a different set of equipment.

Four students were asked to examine error by using a piece of equipment called a potometer. A potometer measures the rate of transpiration in plants. As water is lost from the leaves the plant draws up water to replace it. By measuring the distance moved by an air bubble over a set period of time the rate of transpiration can be measured. This allows transpiration rates under different conditions to be compared.

The students were first asked to set up their potometers and make a mark where the air bubble was at the start of the experiment. After 10 minutes they recorded the distance their bubble had moved. They repeated this process three times to determine a mean result.

Their results are shown in Table 5.3.

<table>
<thead>
<tr>
<th>Student</th>
<th>Distance moved by the air bubble in cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Repeat 1</td>
</tr>
<tr>
<td>Amy</td>
<td>2.1</td>
</tr>
<tr>
<td>Chris</td>
<td>1.4</td>
</tr>
<tr>
<td>PJ</td>
<td>2.2</td>
</tr>
<tr>
<td>Kelly</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Table 5.3 The distance moved by an air bubble in a class potometer experiment.
Questions

1 Which set of data contains more errors? How do you know this from the data?

2 Chris’ data were lower than those of the other members of the group, so the teacher asked him to show how he made his measurements. Figure 5.11 is a picture of how he recorded the distance moved compared to Amy. What did Chris do wrong? What type of error is this? What should he now do?

![Figure 5.11](image)

▲ Figure 5.11 The results of an experiment using a potometer.

3 The teacher asked Kelly to explain how she took her readings. She explained that she took the first reading sitting down, the second standing up, and the third level with the bubble. Why did her method for measuring the bubble introduce errors? What should she have done? Draw a diagram to explain why changing her position would have led to errors in her readings.

4 Why did the rubber tube have grease smeared around it? If this was not present how could it lead to errors in the data?

5 Identify any other potential sources of error in the experiment.

6 The students repeated their experiment with three different conditions:
   a) on a bench with a lamp shining on the plant
   b) on a bench with a fan blowing onto the plant
   c) on a bench with a plastic bag around the plant, creating a humid environment.

For each condition, explain how you think the result would be different and why.
We catch communicable diseases from infected people. They are contagious. HIV/AIDS currently kills over a million people per year and estimates suggest that it has killed about 39 million people in total so far. History reveals much higher numbers of deaths from other communicable diseases. Smallpox is likely to have killed more than 300 million people in the 20th century alone. Spanish flu killed between 50 and 100 million in the same timescale. The Black Death killed around 75 million, reducing the world’s population to around 350 million in the 14th century.

This chapter covers specification points 4.3.1.1 to 4.3.1.9 and is called Infection and response.

It covers communicable diseases caused by viruses, bacteria, fungi and protists. It also covers human defence systems, vaccination, and the discovery and development of drugs, including antibiotics and painkillers.
A pathogen is any microorganism that passes a communicable disease from one organism to another. There are four main types of microorganism that cause disease:

1. viruses, e.g. measles
2. bacteria, e.g. salmonella
3. fungi, e.g. rose black spot in plants
4. protists, e.g. malaria.

All four types of pathogen have a simple life cycle. They infect a host, reproduce (or replicate in the case of viruses), spread from their host and infect other organisms. This process then repeats. Many pathogens can survive without their host for a short period of time, but these are unable to reproduce without their host.

Pathogens are highly adapted to their function. They are very easily passed from one organism to another. We call these highly infectious. An example of a highly infectious pathogen is the measles virus. This is particularly easily spread because it is transmitted in the air. Other pathogens, such as the norovirus (winter vomiting bug), can reproduce very quickly. Others can survive for long periods without a host. An example of this is the Staphylococcus bacterium.

Test yourself
1. Give an example of a viral pathogen.
2. Give an example of a fungal pathogen.
3. Define the expression ‘highly infectious’.
4. Explain the advantage to a pathogen of reproducing quickly.

Show you can...
Explain the life cycle of an infecting pathogen.


### Culturing microorganisms

**TIPS**
- It is important that you can calculate the number of bacteria in a population after a certain time if you are given the mean division time.
- You should be able to express your answer in standard form.
- It is important that you can calculate the cross-sectional area of a bacterial colony using \( \pi r^2 \).
- It is important that you can apply knowledge of sampling techniques to collect representative data.

**Method**

A streak plate is used to produce single isolated colonies of bacteria that can be used for identification.

1. Label the underside of an agar plate with your initials, ensuring that the label is on the edge of the plate and small enough that you can still observe any growth easily.
2. Wear eye protection. Using a blue flame on a Bunsen burner, flame the inoculating loop to sterilise it.
3. Allow this to cool completely.
4. Loosen but do not remove the lid from the culture bottle.
5. Hold the bottle in one hand and the sterile inoculating loop in the other.
6. Remove the lid from the culture bottle using the little finger of the hand you are holding the inoculating loop with. Whilst holding the lid, flame the neck of the culture bottle.
7. Dip the inoculating loop into the culture. Re-flame the bottle neck and replace the lid. The culture bottle can now be set aside.
8. Partially lift the lid of the agar plate. Hold the inoculating loop parallel with the surface of the agar. Streak the culture backwards and forwards across a small area of the agar medium on the left-hand side of the plate by gliding the loop over the surface (don’t dig in).
9. Remove the inoculating loop and close the agar plate. Sterilise the inoculating loop by flaming and allowing it to fully cool.
10. Turn the agar plate through 90°. Use the cooled inoculating loop to streak the agar plate by drawing it through the end of the last streak in three to six parallel lines.
11. Remove the inoculating loop and close the agar plate. Again flame the inoculating loop and allow it to cool.
12. Turn the agar plate through another 90° and again streak across the surface of the agar in three to six parallel lines, passing through the last streaks.
13. Repeat the process one last time by rotating through the final 90°.
14. Remove the inoculating loop and close the agar plate. Place the loop in a sterilising solution.
15. Tape the plate closed using four pieces of tape positioned in ‘north’, ‘east’, ‘south’ and ‘west’ positions and incubate it in an inverted position so that drops of moisture will not fall on the agar. Do not seal the plate completely.
16. Follow your teacher’s instructions on how to clear away. Ensure that benches are clean and hands are washed.
17. After incubation at 25°C observe the colonies produced. If your technique is correct it should look like Figure 6.2.

**Spread of pathogens**

Pathogens have evolved many different ways of passing from one organism to another.

- **Airborne:** the common cold virus is often spread in tiny droplets of water propelled through the air when an infected person sneezes.
- **Through dirty water:** the cholera bacterium is often spread in unsterilised water.
By direct physical contact: this can be sexual or non-sexual. Chlamydia is a bacterial pathogen that is one of the most common sexually transmitted diseases (STDs) in the world. Without treatment with antibiotics this can lead to serious reproductive problems.

Through contaminated food: the *Escherichia coli* bacterium is often spread in uncooked or reheated food. It causes food poisoning.

Passed by another animal: some farmers in the UK believe that badgers can catch the tuberculosis bacterium and pass it to their cattle. We call any animal that does this a vector.

**Viral diseases**

Viral diseases are those caused by a virus. Viruses are microorganisms, but they are not alive because they do not complete all of the seven life processes. They do not respire, for example. They are the smallest pathogens and the most simple, made from a strand of genetic material (DNA or RNA) surrounded by a protein coat. They infect a single cell in a host and use it to copy their genetic material and protein coats. These are then assembled into new virus particles. At this point cells are often full to bursting with new viruses, and they then split open to release new infecting particles to repeat the cycle. Viruses are not alive and so are called strains, rather than species, and they replicate, not reproduce.

**Measles**

Measles is a highly infectious, common viral disease usually transmitted between young children. Its transmission is airborne, so it is passed in tiny droplets when an infected person sneezes. These are breathed in by those around them, who then may become infected. Its symptoms include a fever and a red skin rash. In developed countries babies are immunised against this infection at about one year old. It can infect adults that were not immunised or did not catch it as a child. More serious medical complications can then occur including sterility in adults and foetal abnormalities in pregnant women.
Bacterial diseases

Bacterial diseases are caused by pathogenic bacteria. It is worth remembering that there are many useful bacteria that are not pathogens, including those that live in your digestive system and help you digest your food. All bacteria are prokaryotes. They are larger than viruses but are still only visible using a microscope. They live inside their hosts, often in mouths, noses and throats, but not inside cells as viruses do. They reproduce asexually by binary fission (dividing into two). Many pathogens produce toxins (poisons) as they grow, which irritate the surrounding cells of the host. Bacteria do complete the seven life processes and so are alive.

○ HIV/AIDS

HIV stands for human immunodeficiency virus. This is transmitted when body fluids are shared, often during sex, or by shared use of needles. It can be passed from mother to child in the uterus, during birth or in breast milk. Immediately after infection, the symptoms appear as a flu-like illness. After this, infected people usually show no symptoms. In fact many may not know they are infected at all. Months or years after infection, the virus attacks the body’s immune cells. This means they are then less able to fight off cancers or infections, such as the tuberculosis bacterium. At this point the disease is called late-stage HIV or acquired immune deficiency syndrome (AIDS). There is currently no cure for HIV/AIDS. Infected people are given antiretroviral drugs, which slow the development of the disease.

○ Salmonella

The salmonella bacterium has two different species: *Salmonella bongori* and *S. enterica*. Because they are very similar we just refer to both of them as ‘salmonella’ in normal circumstances. Salmonella infects both cold-blooded and warm-blooded animals, causing fever, cramps, vomiting and diarrhoea. It is normally spread in food that has been prepared in unhygienic conditions, that has not been cooked well enough or that has been reheated. In the UK, poultry are vaccinated against salmonella, to control its spread.

○ Gonorrhoea

Gonorrhoea is a sexually transmitted disease (STD) caused by a species of bacterium called *Neisseria gonorrhoeae*. Together with chlamydia, it is one of the most common STDs in the world. Symptoms include a painful burning sensation when urinating and...
the production of a thick yellow or green fluid (discharge) from the vagina or penis. It used to be easily treated with the antibiotic penicillin, but in recent years some resistant forms have evolved. Other antibiotics can treat this infection. Condoms and other forms of contraception that form a barrier can stop its transmission.

**Test yourself**

11 Name a bacterial disease.
12 How is gonorrhoea treated?
13 Describe the symptoms of salmonella.
14 Describe the symptoms of gonorrhoea.

**Using a key to identify bacterial species**

Use the statement key below to identify the six species of bacteria.

1 It is made of more than one cell .......... Go to question 2.
   It is a single cell ................ Go to question 4.

2 It is made of two cells .......... *Streptococcus pneumoniae*.
   It is made of more than two cells ................. Go to question 3.

3 Bacteria arranged in chains .................. *Streptococcus pyogenes*.
   Bacteria arranged in a cluster .................. *Staphylococcus aureus*.

4 It has no flagella ..................... *Treponema pallidum*.
   It has flagella ........................ Go to question 5.

5 Its flagella are spread all around the cell .......... *Salmonella typhi*.
   The flagella are located to one side of the cell .......... *Helicobacter pylori*.

**KEY TERM**

**Antibiotic** A group of medicines, first discovered by Sir Alexander Fleming, that kill bacteria and fungi but not viruses.
Fungal diseases

Fungi are eukaryotic, like animals and plants, but unlike bacteria. They have evolved a huge range of appearances, from the single-celled yeast fungus to much larger multicellular mushrooms. They are not thought of as plants for many reasons, but in particular they have walls made from chitin rather than cellulose and they produce spores for reproduction rather than pollen and ova. As some fungi grow they extend thread-like structures call hyphae. The largest single organism on our planet is thought to be a fungus growing in Oregon in the USA. It has spread to be over 2.4 miles across. It is not pathogenic to us but does infect and kill trees and other woody plants.

Athlete’s foot

Athlete’s foot is a common fungal infection of people’s feet that causes itching, flaking and blistering. It affects about 15% of the world’s population. It is most commonly transmitted in communal areas where people walk barefoot, such as swimming pools and changing rooms. Modern shoes and socks can keep infected feet warm and moist, which are the ideal conditions for the fungus to grow. Infection can be treated by keeping feet dry and applying an antifungal cream or spray.

Another fungal disease that can affect us is ringworm. This produces a ring-like red rash on infected parts of the body. It is not caused by a worm, although it can look like it has been.

Protist diseases

Protists are eukaryotic microorganisms. Their classification is complicated because they are a large group of dissimilar organisms. They are always unicellular or multicellular without tissues. This separates them from fungi, animals and plants. Protists are perhaps best known as pathogens for causing malaria in humans, but they also cause similar diseases in other vertebrates and also infect plants.

Malaria

Malaria is a disease caused by five separate species of Plasmodium protists. Plasmodium falciparum is the species that causes the most severe symptoms and so has the highest rate of death. Approximately 200 million cases of malaria occur each year the world over. About half
Human defence systems

Your defence against pathogens can be divided into three key areas. We call these ‘lines of defence’ against infection by pathogens. Your immune system is responsible for preventing infection (the first line), detecting it if it does occur, and then responding generally (the second line) or specifically (the third line).

○ The first line of defence
The first line of defence is your body’s natural barriers to infection. These are not specific to the infecting pathogen, and so we describe them as non-specific.

Skin
Your skin is an amazing organ that almost completely covers any outer part of you that is prone to attack from pathogens. As well as this, it insulates you, helps you regulate your temperature and is involved in the way your senses provide you with information. All vertebrates have skin of some sort. It can be thicker on some animals such as cows, and can be used to make leather or similar materials. Fish and reptiles have skin that is formed from hard scales. The skin of mammals can be covered with hair for insulation. When densely
covered, we call it fur. Or it can be covered in feathers in the case of birds. The skin of amphibians is even able to absorb compounds from their surroundings.

Your skin grows in layers with the oldest skin closest to the surface. Dead skin cells are continually dying and dropping off, forming dust. Before they die they are replaced by new skin cells, ready to continue the defence against infection.

Even when damaged, your skin will quickly regrow to prevent infection. When all the layers are cut through, platelets in your blood stick together, forming a scab. This stops the bleeding. At this point the skin around the cut usually becomes red and swells slightly. This is part of your immune response.

Your skin also secretes antimicrobial compounds, which kill some pathogens.

**Lysozymes in tears and saliva**

Your skin does not cover your eyes or mouth. So here the first line of defence could be breached and a pathogen could infect you. To prevent this, your eyes produce tears. These are usually produced to clean your eyes or keep them moist. Tears are mainly made of water and salts. They also contain antibacterial enzymes called **lysozymes**. These break down the cell walls of bacteria. Tears also have antibodies in them. Lysozyme enzymes are also found in your saliva, stopping bacterial infection in your mouth. They are a chemical barrier against infection.

**Hairs and cilia**

Pathogens that are breathed in through your nose and mouth are often stopped before they reach your lungs. Your nose has hairs and produces mucus, which acts as a filter, stopping larger particles containing pathogens. You blow your nose or sniff and swallow, moving this mucus and pathogens into your stomach. Hairs are physical barriers against infection.

If pathogens pass your saliva or hairs in your nose, they are often stopped by the ciliated cells lining the inside of your trachea and bronchi, the tubes that reach down to your lungs. Ciliated cells possess **cilia**, which are tiny hair-like projections that protrude into the airway. In between the ciliated cells are goblet cells. These produce mucus, which they pump into the airway. Many pathogens and other particles that have been breathed in get stuck in this mucus. The ciliated cells beat (or waft) their cilia in a rhythmical pattern, which propels the mucus back up the airway to the back of the throat. A gentle cough then usually moves this down the oesophagus into the stomach. Cilia are physical barriers against infection.

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**KEY TERM**

**Lysozymes** Antibacterial enzymes found in your tears to prevent eye infections.

**Cilia** Tiny hair-like projections from ciliated cells that waft mucus out of the gas exchange system.

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**Figure 6.10** This cut is held together by stitches. It will soon scab over and eventually leave a small scar.

**Figure 6.11** Tears contain enzymes called lysozymes to prevent eye infections from pathogens.

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**TIP**

The movement of cilia is like a Mexican wave in a football match.
Stomach acid
Your stomach acid does not actually digest your food. It provides the correct pH for protease enzymes to start digesting protein. But it also has a crucial role in the first line of defence. It is hydrochloric acid and is strong enough to kill many bacterial pathogens that enter your body through your mouth or nose. It is a chemical barrier against infection.

The second line of defence
Like the first line, the second line of defence is also non-specific. This means your body reacts in the same way regardless of the infection. Because of this, the first and second lines of defence against infection are often called your innate immune system.

Phagocytes
Phagocytes are a type of white blood cell. They take in or engulf pathogens, as well as your own dead or dying cells. They exist in very high numbers in your blood. There are approximately six billion per litre. They are attracted to any area of your body in which an infection is present. When a phagocyte comes into contact with a pathogen it binds to it. The membrane of the phagocyte then surrounds the pathogen and absorbs it into a vacuole within its cytoplasm. Here enzymes are added to the vacuole to break down the pathogen. This is called phagocytosis.

The third line of defence
Unlike the first and second lines, the third line of defence against infection is specific to the invading pathogen. It is therefore called the specific (not innate) immune system.

Lymphocytes
Lymphocytes are a second type of white blood cell. There are between 1.5 and 4.5 million per litre of blood.

Almost all cells have proteins called antigens on their surface. Pathogens have different antigens from those found in your own cells. Your lymphocytes recognise the foreign antigens present on invading pathogens. They produce large numbers of antibodies. This takes several days, during which time you may feel ill. The antibodies are highly specific for the antigen present on the pathogen, which means...
that the shape of the antibody fits perfectly with the shape of the antigen. Antibodies help clump pathogens together so that they can then be engulfed and destroyed by phagocytes more easily. Several days later enough of the pathogen will normally have been destroyed and you are likely to be feeling better.

![Figure 6.15 How an antibody fits onto the antigen of a pathogen.](image)

If you are infected a second time with the same pathogen your lymphocytes will recognise its antigens and be able to produce larger numbers of antibodies more quickly. We call these white blood cells 'memory' lymphocytes. This is likely to mean you won’t fall ill from the same pathogen twice. How do we get colds every winter, then? This is because there are several hundred different strains of common cold viruses that all have different antigens. You are not likely to have been infected by the same one, but lots of different ones that have similar symptoms.

**Antitoxins**

Many pathogens produce toxins that also make you ill (as well as the pathogen itself). To defend against these specific toxins, your lymphocytes can produce a special type of antibody called an antitoxin. This will bind with and neutralise the toxin helping you feel better.

**Test yourself**

22 Give an example of the first line of defence.
23 Name the two types of white blood cell.
24 Describe how stomach acid stops infection.
25 Describe the difference between chemical and physical barriers.

**Show you can...**

Explain how the first, second and third lines of defence stop infection.
Vaccination

It is likely that you will have been vaccinated against a number of diseases since you were born. Typically you may have had the measles, mumps and rubella (MMR) vaccine at about 12 months old, and a second combined vaccine for diphtheria, tetanus, whooping cough and polio at about 3 years. These are all life-threatening diseases, and so vaccination is important. If the vast majority of people in a population have a vaccination, then even if a small number of people become infected the disease is not likely to spread. This is called herd immunity. The reverse is also true. If few people have a vaccine and a small number become infected the disease will spread much more quickly.

A vaccine is a small quantity of a dead, inactive or genetically modified version of a pathogen. Crucially it must have the same antigens as the pathogen, or your body would not recognise the pathogen later. You are injected with this and your primary immune response begins. Phagocytes start engulfing the pathogen. Lymphocytes produce antibodies and antitoxins. Because this process takes several days, you may feel ill after a vaccination.

However, if the same pathogen were to get past your first line of defence and infect you in the future, your ‘memory’ lymphocytes would respond by producing antibodies and antitoxins fast enough for you not to fall sick. This is your secondary immune response. Thus, vaccinations act as gentle warnings for your immune system in case you are infected later in life.

For many vaccines, you are likely to have had booster injections several years after the first injections. These serve as a timely reminder for your immune system and ‘refresh’ your memory lymphocytes.

KEY TERM
Vaccine A medicine containing an antigen from a pathogen that triggers a low level immune response so that subsequent infection is dealt with more effectively by the body’s own immune system.

TIPS
- It is important that you can explain the use of vaccinations to prevent disease. You do not need to know specific times or dates for getting vaccines, though, or their side effects.
- The term ‘immunisation’ means “becoming immune to a pathogen”. This can be caused by vaccination but also naturally if you become infected by a pathogen.

Test yourself

26 What does ‘MMR’ in the MMR vaccine stand for?
27 Which cells produce antibodies?
28 Define the term ‘vaccine’.
29 Describe the difference between antigens and antibodies.
A drug is any substance that has a biological effect on the organism taking it. We do not normally include foods in this definition, even though many do affect people. Some drugs are natural, such as nicotine in tobacco. Others are manufactured, such as Viagra. Some have a positive effect on the taker, such as medicines, while others have negative side effects, such as cocaine. Some drugs are recreational. They are taken to alter a person’s mood or emotions. Legal recreational drugs include caffeine and nicotine. Illegal recreational drugs include cannabis and cocaine.

### Antibiotics

Antibiotics are a very important group of medicines which kill bacteria and fungi. They have no effect on viruses and so are never prescribed for the common cold or other viral diseases.

It is worth remembering that antibiotics and antiseptics are different. Antibiotics are drugs that are taken to kill bacterial or fungal diseases. Antiseptics are substances applied to the skin or other external surfaces to destroy pathogens. As such, antiseptics are not drugs.

Different antibiotics attack bacteria in different ways. Penicillin (see below) is a commonly used antibiotic. It makes the cell walls of the bacteria weaker, and so they burst and are killed. Other antibiotics alter bacterial enzymes, and others stop bacteria from reproducing.

#### Penicillin and Alexander Fleming

Sir Alexander Fleming (1881–1955) first discovered penicillin in 1928. He won the Nobel Prize for this discovery and penicillin has saved countless numbers of lives ever since. Fleming returned to his laboratory where he was studying species of *Staphylococcus* bacteria. Legend has it that one of his Petri dishes was mistakenly left open and had accidently been contaminated by the fungus *Penicillium notatum*. Where the fungus grew the *Staphylococcus* bacteria did not. Instead of simply throwing the Petri dish away, Fleming realised that the fungus was naturally producing a chemical that killed bacteria. Fleming then isolated the first antibiotic drug, and it was called penicillin after the fungus from which it originated. Thus, the discovery of penicillin was one of science’s fortunate mistakes.
Investigate the effect of antiseptics or antibiotics on bacterial growth using agar plates and measuring zones of inhibition

In this practical you will investigate the effect of antiseptics on the growth of bacterial colonies.

**Method**

1. Label the underside of a Petri dish, containing a sterile nutrient medium, with your initials and date and divide it into four quarters, labelled A–D.
2. Wear eye protection. Using aseptic technique and a sterile pipette add a few drops of a bacterial culture to the centre of the nutrient medium and replace the lid.
3. Place the pipette in disinfectant.
4. Partially lift the lid of the Petri dish and use a sterile spreader (disposable or flamed) to spread the bacterial culture over the entire surface of the nutrient medium using a side-to-side motion. Ensure you glide it across the surface and do not push too heavily down on it.
5. Replace the lid of the Petri dish.
6. If the spreader is disposable, add it to the disinfectant, or flame the spreader using disinfectant.
7. Allow the culture to dry.
8. While this is happening flame a pair of forceps in disinfectant. Allow them to cool.
9. Use the forceps to pick up a sterile filter paper disc.
10. Using aseptic technique, dip the filter paper disc into the antiseptic sample. Remove and wait until it has stopped dripping.
11. Partially lift the lid of the Petri dish and then carefully place the disc on the A section of the nutrient medium.
12. Flame the forceps and repeat with antiseptic samples B, C and D.
13. Tape the plate closed and incubate it in an inverted position.

**Analysing the results following incubation**

1. Draw the appearance of the resulting plate.
2. Record in a table the diameter of the zones of inhibition of growth for each antiseptic.
3. Work out the area of the zones of inhibition using the formula:
   \[ \text{area} = \pi \times r^2 \]
4. Determine the mean for the area of the zone of inhibition for each antiseptic.
5. Produce a bar chart of the class mean results.
6. What can you conclude about which antiseptic works the best?

**Taking it further**

This investigation could be altered to examine the effectiveness of different concentrations of antiseptics or of different antibiotics. Instead of using antiseptics, you could place a mast ring on the surface of the nutrient medium. Following incubation the zones of inhibition could be measured to establish which antibiotics prevented the most bacterial growth.

**Antibiotic resistance**

Since Fleming’s discovery scientists have developed a large number of other related antibiotics. These have saved many, many lives in recent years and led to the near removal of some major diseases such as tuberculosis. However, until very recently, we had not discovered any new antibiotics in 30 years. During this time some pathogens have been evolving to be resistant to our antibiotics. Because penicillin was the first to be discovered and used, pathogens have had longer to evolve resistance against it. This is evidence for evolution.
Drug companies are working extremely hard to find new antibiotics or alternatives to them.

- **Painkillers**

Painkillers are drugs that relieve pain. They are not the same as anaesthetics, which you may have had at the dentist’s or doctor’s. These stop all sensation from a particular place (local) or from your whole body (general).

Some painkillers are naturally found in plants. Aspirin comes from the bark of the willow tree. The naturally occurring compound is called salicin and was first discovered in 1763 by Edward Stone (1702–1768). It was not manufactured as aspirin until 1897. It is now one of the most widely used medicines in the world, with over 40 000 tonnes consumed each year. As well as relieving pain, it can reduce fever, swelling and inflammation. It is also used as a preventative drug for reducing the risk of heart attacks.

Other painkillers have been manufactured. A second common painkiller is paracetamol. Like aspirin, this is a mild painkiller often used to stop headaches or minor pain in other parts of the body. It is a major ingredient in many cold and flu remedies. Unfortunately, it is easy to take too much paracetamol at a time, which can cause fatal liver damage. This is why it is very important not to take more than the stated dose.

Both aspirin and paracetamol are ‘over-the-counter’ medicines, which means you can buy them in small numbers in chemists and supermarkets. Other stronger painkillers exist, such as tramadol and morphine. The use of these can only be prescribed by a doctor or used in accident and emergency situations.

**Test yourself**

30 Name the first antibiotic.
31 Which organism does aspirin come from?
32 Describe the difference between antiseptics and antibiotics.
33 Describe another medical use for aspirin.

**Show you can...**

Explain what was significant about the manner in which Fleming made his discovery.

**Discovery and development of drugs**

In the course of our history we have found naturally occurring drugs and manufactured new ones. Some drugs, such as digitalis, are found in plants. Digitalis is used to treat people with irregular heartbeat and comes from the foxglove plant.
Modern drug development

Drug development is the process of identifying a new drug, testing it and then manufacturing it for sale. This is a very costly and time-consuming process. To get a drug to the stage at which it can be tested, the development is likely to take many years and hundreds of millions of pounds. Drug companies are some of the largest in the world. Many potential drugs don’t pass though the stages described below. From perhaps ten thousand possible drugs only 10 (0.1%) may ever get to be tested on humans.

The first stage of drug development involves computer modelling. The structure of the drug and the interactions it might have on naturally occurring substances in the body are looked at on a computer.

The second stage of drug development involves testing in the laboratory. This may include testing on live cells taken from an organism and grown in a Petri dish. It may also include testing on animals. The results from these tests are used to see how the drug may affect humans.

The third and final stage involves clinical trials on humans. There are three phases here. In the first the drug is tested on a small number of healthy volunteers to determine whether it is toxic and to identify safe dosing volumes. In the second phase the drug is given to small numbers of sick patients to test how well it works (its efficacy). Finally, in phase three trials it is given to a large number of patients to finalise safe doses and efficacy. If a drug passes all of these stages it will be given a licence and then can be manufactured and sold.

Some of these trials are described as double blind. This is because the patients are randomly allocated to receive either the drug or a placebo (which looks like the drug but does not contain it) and the doctors also don’t know which patients are receiving which. This eliminates the placebo effect, in which some people feel better simply because they think they have taken the drug when they haven’t. Remember when your parents rubbed your bumped knees when you were a child and said, “There, there. It’s okay now.” And it was!

TIP

Draw a flow diagram of the process of drug development to help you remember it.

KEY TERMS

Computer modelling Using computer software to theoretically examine or test.

Efficacy How effective a drug is.

Double blind trial A medical experiment in which the patients and doctors do not know who has been given the drug and who has been given the placebo.

Placebo A medicine that has only psychological effects.

Test yourself

34 What is the first stage of drug development?
35 Describe the placebo effect.
Chapter review questions

1. Define the term ‘communicable disease’.
2. Name the four types of pathogen that can cause communicable diseases.
3. Give an example of a disease caused by a fungus.
4. Give an example of a disease caused by a protist.
5. What does HIV/AIDS stand for?
6. Name the scientist who first discovered antibiotics.
7. Name the microorganisms upon which antibiotics don’t work.
8. Explain the difference between antibiotics and antiseptics.
9. Explain why medicines are often expensive.
10. Describe how to make a streak plate.
11. Describe the structure of a virus.
12. How is salmonella often transmitted?
13. What are the symptoms of gonorrhoea?
14. How is athlete’s foot treated?
15. What are the symptoms of malaria?
16. Describe how the transmission of malaria is reduced.
17. Describe how stomach acid acts in the first line of defence.
18. Explain how your immune system helps you ‘remember’ your previous infections.
19. Describe what a vaccine is.
20. Explain the idea of herd immunity.
21. Explain the purpose of booster injections.
22. Describe how antibiotics were first discovered.
23. Describe how cilia and goblet cells prevent infection.
24. Describe how phagocytes prevent infection.
25. Describe how lymphocytes prevent infection.
26. What is the first step in drug development?
27. Define the term ‘efficacy’.
28. Explain what a double blind trial is.
29. Describe how we abbreviate the binomial names of organisms, including microorganisms.
Practice questions

1 Figure 6.25 shows data from a drug trial involving a new asthma medicine called Breathrite.

![Graph showing data from a drug trial involving a new asthma medicine called Breathrite.]

a) Before the drug was trialled using people it was tested in the laboratory. What is the purpose of these tests? [1 mark]

b) The drug trial used a double blind test. Doctors tested the effectiveness of Breathrite against a placebo using two groups of volunteers over 12 weeks.

i) What is a placebo? [1 mark]

ii) Why is a placebo used? [1 mark]

iii) Describe what a double blind trial means. [1 mark]

c) It is important that the two groups of volunteers are similar. Give one factor that should be similar in both groups. [1 mark]

d) Over the 12-week period, how much did the lung capacity of the volunteers increase in those who were given Breathrite? [1 mark]

2 In 2014 the largest Ebola epidemic in history broke out and affected a number of countries in West Africa. Ebola is caused by the *Ebola* virus (Figure 6.24).

![Image of the Ebola virus.]

a) Give the term given to organisms like *Ebola* that cause disease. [1 mark]

b) Describe how viruses like *Ebola* cause illness. [1 mark]

c) Currently there are no cures for Ebola.

i) Why don’t antibiotics get rid of Ebola? [1 mark]

ii) Some of the symptoms of Ebola are headaches and muscle pain. Suggest what might be given to someone suffering from Ebola to relieve the symptoms. [1 mark]

d) Scientists are trying to create a vaccine for Ebola by using an inactive form of the *Ebola* virus. Explain how this would allow a person to become immune to the disease. [3 marks]

3 a) Malaria is a disease cause by what type of pathogen?

A Virus  B Bacteria  C Fungi  D Protist

b) Which two of the following are symptoms of this disease?

A Fever  B Vomiting  C Flaking skin  D Swollen feet

4 The influenza virus is a microorganism that can cause the flu. The flu is an infectious disease, which can be spread quickly from person to person.

a) i) Name two other microorganisms that can cause disease. [2 marks]

ii) Describe two ways in which microorganisms like influenza can be passed on from one person to another. [2 marks]

iii) Suggest a simple hygiene measure that can be taken to reduce the spread of the flu. [1 mark]

b) The body has several non-specific ways of preventing infection from microorganisms. Copy and complete Table 6.1 by naming the part of the body described. [3 marks]

<table>
<thead>
<tr>
<th>How entry of microorganisms is prevented</th>
<th>Part of the body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contains acid to destroy microorganisms</td>
<td></td>
</tr>
<tr>
<td>Acts as a barrier</td>
<td></td>
</tr>
<tr>
<td>Contain ciliated cells to trap bacteria</td>
<td></td>
</tr>
</tbody>
</table>

5 The effect of three antiseptics on bacterial growth was measured.

Describe a method you could use to investigate this. You should include:

a) what you would measure [6 marks]

b) safety precautions you would take.
Evaluating the risks and benefits

The World Health Organization (WHO) has the goal of eliminating measles in WHO regions between 2015 and 2020. Measles is a highly infectious disease caused by the measles virus and is spread through droplet inhalation and contact with infected people and surfaces. Measles is not just a condition that causes spots; about one in five children infected with it experience complications and one in ten can end up in hospital. In rare cases measles can cause death. Anyone can catch measles, and there is no specific treatment for it. The most effective way of preventing it is to have two doses of the combined MMR (measles, mumps and rubella) vaccination, which gives almost total protection from the disease.

In recent years there has been a global decline in MMR vaccinations, especially in Western Europe and the USA. This has contributed to over 22,000 cases of measles worldwide and has raised concerns that, far from being eliminated, cases of measles are actually increasing. According to WHO, a growing number of parents are refusing to vaccinate their children. This is sparking a global debate over whether vaccinations should be compulsory.

So what do you think?

In making any decision a number of factors need to be examined. These can be split into advantages, disadvantages and risks. These need to be considered on a personal level for the person making the decision, as well as in terms of the impact on society as a whole.

Questions

1. Copy the table below and use the internet and other sources of evidence, such as medical leaflets and newspaper articles, to help you determine the advantages, disadvantages and risks of compulsory vaccination programmes.

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vaccination compulsory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vaccination voluntary</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

2. Make a decision on what you think and write a letter to the Government expressing your views on compulsory vaccinations. Ensure you support your views with reasons and evidence.

3. Using diagrams and your knowledge of the immune system, explain how the MMR vaccination creates immunity to measles.
Monoclonal antibodies

What do pregnancy tests, HIV/AIDS diagnosis test kits and cancer treatments have in common with your immune system? One answer is that they all involve antibodies. These are produced by your immune system to bind to pathogens. Scientists have cleverly copied this process and manufactured antibodies that can bind to almost any substance. These include hormones in pregnancy tests, and proteins on the HIV/AIDS virus and some cancer cells.

This chapter covers specific points 4.3.2.1 and 4.3.2.2 and is called Monoclonal antibodies.

It covers the production and use of monoclonal antibodies.

This whole chapter is Higher tier only.
Producing monoclonal antibodies

Antibodies are proteins produced by our white blood cells to recognise and attach to pathogens. They help clump them together for different white blood cells to engulf and destroy them with enzymes. Antibodies are made in response to antigens on the surface of a pathogen. Antigens are also proteins, and antibodies are produced to fit the exact shape of each different antigen.

Recently we have discovered that antibodies can be made to bind to almost any substance, whether it is from a pathogen or not, provided it has an antigen. The antibodies are very specific for the antigen to which they bind. Once antibodies are bound to this substance it can be more easily detected and, if appropriate, removed. This has meant that we can use antibodies for a large range of medical and biochemical tests and treatments.

To use monoclonal antibodies for medical tests and treatments we must first produce large numbers of identical antibodies. Because they are identical we call them ‘mono’ (one) ‘clonal’ (identical copies). They were first developed by Georges Köhler (1946–1995) and César Milstein (1927–2002) in 1975 and Köhler and Milstein won the Nobel Prize several years later.

- **Procedure**

An antigen is injected into a mouse. The mouse’s immune response begins and after several days its white blood cells produce antibodies specific to the injected antigen. Spleen cells are collected from the mouse in a relatively simple operation. Spleen cells contain the antibody-producing white blood cells.

These spleen cells are fused with myeloma cells to form hybridoma cells. Myeloma cells are white blood cells that have turned cancerous. This means they can be grown in culture in the laboratory and because they are cancerous they will keep on growing and dividing indefinitely. There are some cancerous cells that are growing in culture long after the people they were collected from have died.

Hybridoma cells are collected and then also grown in a culture medium. Any myeloma cells that have not fused to form hybridoma cells cannot survive in this medium and so die. As with the myeloma cells, the newly formed hybridoma cells can normally then be grown indefinitely in their growth medium. They continue to produce in large amounts monoclonal antibodies to the original antigen that was injected into the mouse. These are isolated from the growth medium by centrifugation, filtration and chromatography.
A common use of monoclonal antibodies is in pregnancy tests. Here they are used to identify very small concentrations of a hormone called HCG, which is present in the urine of pregnant women. The monoclonal antibody is stuck to the ends of a small strip of paper onto which a woman urinates. If she is pregnant she will be producing HCG and some will be excreted in her urine. This immediately binds with the monoclonal antibody on the end of the strip of paper and turns a different colour. This indicates that she is pregnant.
Monoclonal antibodies are also used for other diagnostic tests. They are used to diagnose hepatitis, HIV/AIDS, herpes and chlamydia infections. As well as this, they can be used to test for hundreds of other substances, including levels of other hormones in the blood. As a part of this process monoclonal antibodies can be chemically joined (bound) to fluorescent dyes. When looked at under ultraviolet light these fluorescent dyes glow, indicating the presence of an antigen.

Explain how monoclonal antibodies can be used to treat diseases.

Monoclonal antibodies are also used to treat diseases. This use is therefore more than diagnostic. Monoclonal antibodies have been designed to help your immune system attack cancerous cells, stop those cells dividing and also carry toxic drugs or radiation to them. The drugs need to be toxic to kill the cancer cells. Crucially, these monoclonal antibodies will only bind to cancerous cells, leaving those normal cells surrounding the cancer free from the toxic drug or radiation.

Unfortunately the medical testing of monoclonal antibodies has produced some unexpected side effects. They were originally thought to be a ‘magic bullet’ capable of targeting any individual pathogen. Because of these side effects they are not yet as widely used in medicine as was originally predicted. This is a good example of how effective our testing of new drugs and medical procedures is.

Test yourself

4. Describe the uses of monoclonal antibodies.
5. Name the hormone that is detected by pregnancy tests.
6. Name an infection that monoclonal antibodies can detect.
7. Describe how doctors know whether a pathogen is present.
8. Describe why monoclonal antibodies are not yet a ‘magic bullet’.

Figure 7.3 Herceptin is a monoclonal antibody that binds to the surface of breast cancer cells and stops their growth.

KEY TERM
Diagnostic test A medical procedure that tells a patient whether they have an infection or condition.
Chapter review questions

1. What type of biological molecule are monoclonal antibodies?
2. Describe the function of antibodies.
3. Describe what an antigen is.
4. Define the term 'monoclonal antibody'.
5. Name the two scientists who first discovered monoclonal antibodies and were awarded the Nobel Prize for doing so.
6. Describe the process of making monoclonal antibodies.
7. Name the two cell types that are fused together to make hybridoma cells.
8. Give two conditions that monoclonal antibodies can test for.
9. Give one use for monoclonal antibodies other than tests.
10. What makes antibodies recognise antigens?
11. Describe the discovery that started the development of monoclonal antibodies to be used for many different purposes.
12. Explain why spleen cells are used.
13. Define the term 'myeloma cell'.
14. Explain how monoclonal antibodies are used in pregnancy tests.
15. Explain why monoclonal antibodies have not been the 'magic bullet' some scientists thought they might be.

Practice questions

1. In Figure 7.2 you saw how monoclonal antibodies can be made.
   a) The first stage involves injecting a mouse with an antigen.
      i) What is an antigen? [1 mark]
      ii) Describe how the mouse’s immune system reacts to injection of the antigen. [3 marks]
   b) Myeloma cells are white blood cells that have become cancerous. Why are these cells used? [1 mark]
   c) What is the name for the cells produced by fusing spleen cells with myeloma cells? [1 mark]
      A) Carcinoma  B) Hybridoma  C) Melanoma  D) Hyperdoma
   d) Name two different uses of monoclonal antibodies. [2 marks]

2. Herceptin is a monoclonal antibody used to treat breast cancer.
   a) Use the detail from Figure 7.4 to explain how Herceptin can slow the growth of cancer cells. [4 marks]
   b) Explain the advantages of using monoclonal antibodies to treat cancer compared with conventional treatments. [2 marks]
Many of us know about diseases that infect humans. You probably know that HIV/AIDS is a virus, tuberculosis is caused by a bacterium and athlete’s foot is caused by a fungus. But when was the last time you thought about a disease of another species? Cats can catch the feline herpes virus. Dogs can catch mange. Even plants can catch diseases too. Dutch elm disease has killed more than 25 million elm trees in the UK alone. Very few still live. Some scientists think that almost all species of life on Earth may have a pathogen. Even some of the pathogens themselves may have their own pathogens!

This chapter covers specification points 4.3.3.1 and 4.3.3.2 and is called Plant disease.

It covers detection and identification of plant diseases and plant defence responses.
Like humans and other animals, plants can catch communicable (infectious) diseases. Many plant diseases are caused by the three main pathogens: viruses, bacteria and fungi. Plants, like us, are also susceptible to infection from small worms and insects. Plant pathogens can be spread in water or air, through sap, by insects or worms that eat part of the plant, through pollen and seeds, and directly to organisms that come into contact with them.

**Viral diseases**

**Tobacco mosaic virus**

The tobacco mosaic virus is a common pathogen of many plants, including tobacco and tomato plants. It gets its name because it causes the leaves of infected plants to have discoloured patterns on their leaves that resemble mosaics. This reduces the infected plant’s ability to photosynthesise and therefore produce the glucose needed for growth. This virus is particularly good at surviving without a host provided that the temperature of its environment remains below about 40 °C. So it can remain in the soil and infect other plants that are planted or grow there. The tobacco mosaic virus costs an estimated loss of 60 billion US dollars each year.

**Bacterial diseases**

**Pseudomonas syringae**

This bacterial species and related pathogens infect a number of plant hosts. They attack snapdragons, primulas and delphinium flowering plants, as well as celery, cucumbers, plums and other fruits. They produce discoloured leaves, reducing the ability of their host to photosynthesise. They also increase the plant’s susceptibility to frost damage.

**Fungal diseases**

**Rose black spot**

Rose black spot is a disease caused by the fungus *Diplocarpon rosae*, which infects the leaves of many roses. Like the tobacco mosaic virus, this fungus also marks the leaves of infected plants, turning them purple or black. This reduces their ability to photosynthesise and produce the glucose needed for life processes. Heavily marked leaves simply die and drop from the plant. Their spread is prevented by burning all infected leaves and stems after they have been removed from the plant. Infection can be treated by applying an antifungal chemical usually in a spray.
Rice blast
Rice blast is caused by the fungus *Magnaporthe grisea*. It can also infect wheat, rye and barley. Each year it is estimated to destroy enough rice to feed more than 60 million people. It has huge medical and economic consequences. It produces coloured lesions (rough bumpy areas) on rice stems and leaves. Scientists are developing chemical treatments but also trying to grow plants that are genetically resistant to it.

Activity  
Dutch elm disease
Dutch elm disease is one of the most serious plant diseases in the world. It has killed over 60 million elms in Britain since the start of the epidemic and is still continuing to spread. Use the internet to research the following:
- what Dutch elm disease is caused by and how it is spread
- the symptoms of the disease in elm trees
- how scientists are trying to control the disease
- which other organisms live in elm trees and depend upon them.
Present your findings as a poster or pamphlet.

Other diseases

Nematode worms
Nematodes are small, multicellular, worm-like animals. Many live freely in the soil and are harmless to plants. Others are parasites in plant roots. Two species of potato cyst nematode, *Globodera*, are found widely in Europe and North America and cause lost yields of up to 300 million US dollars per year.

Other plants
Some plants, such as mistletoe, are parasites that infect other plants. They are parasitic because they steal from their host without giving anything in return. Mistletoe fruits are eaten by birds. Their droppings containing the seeds from the fruits are dropped onto branches of other trees. Here the seeds stick and germinate. They then send root-like structures into the branches of the host and tap into its water transport system.

Aphids
Aphids are tiny insects that are often found in large numbers sucking the sap from the stems of plants. They infect many plants, including some crops, and are often found on roses in gardens. They reduce the rate at which plants grow, encourage them to wilt and make their leaves curl and discolour. Aphids are eaten by ladybirds, so many gardeners try to promote the numbers of ladybirds in their gardens rather than spray insecticides.
Deficiency diseases

Plants, like us, require small quantities of some substances to live healthily. You will learn in the next chapter that plants need magnesium ions to make chlorophyll for photosynthesis. Plants need to absorb this and other substances through their roots. These are usually in lower concentrations in the soil than in the plant, and so active transport is required. If plants do not absorb enough magnesium ions their leaves turn yellow. This is called chlorosis. They are then much less able to photosynthesise and produce the glucose they need to live. Plants also need nitrate ions to make proteins. Without sufficient nitrates, plants suffer from stunted growth.

Infected plants can show a wide variety of symptoms of disease, including:
- stunted growth
- spots or growths on leaves or stems
- malformed stems or leaves
- discolouration
- areas of decay (rotting)
- the presence of pests.

Gardeners identify diseases by looking in books or on the internet, or by taking their infected plant to a garden centre or laboratory for help. Many different techniques, including monoclonal antibodies, are used to identify the disease. Once the cause is known the correct treatment can be followed. This is obviously very important for both gardeners and farmers.

The impact of nutrient deficiencies on plant growth

Describe how you could design a method that uses the following equipment to investigate the impact of nutrient deficiencies on plant growth. You do not have to use it all.

- Soil A deficient in nitrogen
- Soil B deficient in potassium
- Soil C deficient in magnesium
- Soil D deficient in phosphorus
- Soil E nutrient rich
- 25 radish plant seedlings
- 5 plant pots of identical sizes
- 200 cm³ and 100 cm³ beakers
- Mass balance
- Water
- Ruler

Activity

Show you can...

Explain the effects of the tobacco mosaic virus, rice blast and black spot.

Test yourself

1. Give an example of a plant disease caused by a virus.
2. What type of pathogen causes black spot?
3. Describe how a gardener would identify an infection.
Plant defence responses

Just as in animals, plants and their pathogens have been fighting an evolutionary battle. Pathogens have evolved to infect plants and plants have evolved in return to defend themselves.

○ **Preventing infection**

Plants have cell walls that are thickened with cellulose to strengthen them and provide structure. This also acts as a barrier to resist the infection of pathogens. Leaves have a waxy cuticle to control water loss during transpiration. This waxy cuticle also acts as a barrier to defend plants. Larger stems also have a thicker layer of dead cells that surround them. This forms the bark on trees. Rather like your skin, this can fall off the plant, taking pathogens with it.

○ **After infection**

A small number of plants such as mint and witch hazel possess naturally occurring antibacterial compounds to stop bacterial infections. Scientists have managed to identify some of these plants and their compounds, and some are now used as antiseptics.

○ **Other adaptations**

Many plants produce chemicals that are poisonous to the herbivores that might eat them. Poison ivy and deadly nightshade are well-known examples of plants that do this. These are two that are poisonous to us as well. The foxglove produces a chemical called digitalis, which is used to treat irregular or fast heartbeat. This is produced by the plant to stop it being eaten.

Other plants have evolved different strategies. Many have spines or thorns to prevent them being eaten. Some like the *Mimosa pudica* plant quickly droop and fold their leaves when touched. This happens quickly enough for small insects such as grasshoppers to fall off. Species of *Passiflora* plant have evolved to possess spots on their leaves that look like the eggs of butterflies. Adult butterflies that are ready to lay their eggs will avoid these leaves to minimise any competition for their offspring.

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**Test yourself**

4 Name the compound that thickens plant cell walls.
5 What do plants possess that resembles your skin?
6 Describe the advantage to *Passiflora* plants of having spots on their leaves.
7 Describe how the foxglove defends itself.
Chapter review questions

1. Name a common viral infection of a plant.
2. Name a common fungal infection of a plant.
3. Name a plant parasite.
4. Name the type of insect that commonly infects plants such as roses.
5. Describe what aphids do to the plants they infect.
6. Name a natural predator of aphids.
7. Describe the adaptation that ivy and deadly nightshade have to protect themselves from grazing herbivores.
8. Describe the symptoms of a tobacco plant infected with the tobacco mosaic virus.
9. Describe how the tobacco mosaic virus is adapted for its function.
10. Describe the symptoms of a plant infected with the rose black spot fungus.
11. How is infection by the rose black spot fungus prevented and treated?
12. Explain the effects of an aphid infestation on a plant.
13. Why are nitrate ions needed by plants?
14. Why is magnesium needed by plants?
15. Name the process by which plants absorb mineral ions from the soil and explain why they use this process.
16. Describe an experiment in which you could use soils without key nutrients to observe deficiency diseases.
17. Describe how plants might protect themselves from infection.
18. Explain the consequences to a plant that has discoloured leaves because of infection by the tobacco mosaic virus.
19. Suggest why the tobacco mosaic virus is an important plant disease.
20. Name the deficiency disease caused by plants not absorbing enough magnesium.
21. Suggest the general symptoms that you might expect to find in a plant infected with a disease.
22. Suggest some ways in which gardeners might identify diseases.
23. Give the names of two plants that possess naturally occurring antibacterial compounds.
24. Name the compound in foxglove that is used to treat irregular or fast heartbeat.
25. Explain why the *Passiflora* plant has evolved to have spots on its leaves.
Practice questions

1 Phytophthora, more commonly known as pepper blight, is caused by a fungus. The fungus occurs naturally in most soils and can infect pepper plants and other crops at most stages of growth.

a) Name another fungal disease that can affect plants. [1 mark]

b) It is not just fungal disease that can harm plants. Name another type of plant pathogen. [1 mark]

c) Figure 8.6 shows the incidence of pepper blight after soil saturation.

\[
\begin{array}{|c|c|c|c|c|c|}
\hline
\text{Days after heavy rain} & 2 & 3 & 4 & 5 & 6 \\
\hline
\text{Disease incidence in \%} & 0 & 10 & 20 & 30 & 40 \\
\hline
\end{array}
\]

\(\text{ Figure 8.6 }\)

i) What was the incidence of disease at 6 days? [1 mark]

ii) Describe the incidence of infection from 3 to 5 days. [3 marks]

iii) Between which two days was there the most dramatic increase in the incidence of disease? [1 mark]

d) Use the data to suggest how pepper blight is spread. [3 marks]

2 Tobacco mosaic virus (TMV) is named after the first tobacco plant found to be infected. However, today it is known to infect 350 different species of plant, including tomatoes. Figure 8.7 shows leaves from an infected and a healthy tomato plant.

\(\text{ Figure 8.7 }\)

a) Describe the difference in appearance in the two leaves. [2 marks]

b) Explain why the symptoms seen in Figure 8.7 would mean infected plants are less likely to survive. [3 marks]

3 A student investigated the effect of mineral ions on the growth of duckweed. Figure 8.8 shows the apparatus that was used.

\(\text{ Figure 8.8 }\)

Three beakers were set up each containing a different culture solution.

- Beaker A has all mineral ions present.
- Beaker B has all mineral ions except nitrate.
- Beaker C has all mineral ions except magnesium.

After 4 weeks the duckweed was removed from each of the beakers. Beaker A showed normal healthy growth.

a) Describe the appearance of the duckweed in:

i) Beaker B [1 mark]

ii) Beaker C [1 mark]

b) Explain the reasons for the difference in appearance of the plants. [4 marks]

c) Which part of the plant is adapted to take in minerals? [1 mark]

d) Explain why the duckweed would not have been able to absorb the mineral ions from the culture solution by diffusion. [1 mark]

e) What process would be most likely to be used by the duckweed to absorb the mineral ions? [1 mark]

\(\text{A Active transport \quad C Osmosis }\)

\(\text{B Diffusion \quad D Facilitated diffusion }\)
Drawing conclusions from data

An experiment was carried out on the effectiveness of essential oils from three different plants on the growth of *Escherichia coli* bacteria in liquid culture. As the bacteria grow, the liquid changes from clear to increasingly cloudy (turbid). A spectrophotometer is used to determine turbidity (cloudiness) by measuring the amount of light that passes through the liquid culture. This is called percentage transmission (%T). The more bacteria present, the more turbidity and therefore the less light that can pass through.

![Figure 8.9](image)

▲ Figure 8.9 The equipment used to investigate the effectiveness of three different essential oils on the growth of *E. coli* bacteria.

The results are shown in Table 8.1.

Table 8.1 The transmission of light over time through bacterial cultures with added essential oils.

<table>
<thead>
<tr>
<th>Time in minutes</th>
<th>Control</th>
<th>Grapeseed</th>
<th>Rosemary</th>
<th>Peppermint</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
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<tr>
<td>30</td>
<td>100</td>
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<tr>
<td>300</td>
<td>23</td>
<td>9</td>
<td>52</td>
<td>100</td>
</tr>
</tbody>
</table>

Questions

1. Why was a control used in the experiment? Suggest what this could have been.
2. Explain why the transmission of light in the control decreased over time.
3. Which essential oil has an anomaly in its data, and what is this?
4. Plot a graph of the data with time along the x-axis and transmission of light along the y-axis. Draw a different line for each condition tested and draw a key to identify them. Do not include the anomalous result in your trend line.
5. Describe the trends shown by the data. Compare the effectiveness of the different essential oils and quote data in your answer.
6. Work out the reduction in the transmission of light for each condition over the 300 minutes.
7. In Chapter 6 you carried out a practical to examine the effectiveness of different antiseptics on preventing bacterial growth. Write a method to describe how this practical could be adapted to test the antibacterial properties of ginger, witch hazel and tea tree oil.
Imagine being able to make your own food. Not make it from ingredients in your kitchen, but actually make the ingredients themselves. This is what plants and other photosynthesising species can do. In fact, almost all life on Earth depends upon their ability to do this. They feed themselves by storing the Sun’s light as glucose during photosynthesis. Interestingly we could not live here without them, but they would grow equally well without us. In fact they might grow a little better!

This chapter covers specification points 4.4.1.1 to 4.4.1.3 and is called Photosynthesis.

It covers photosynthesis, its rate of reaction and the uses of the glucose that it produces.
Previously you could have learnt:

- that plants make carbohydrates in their leaves by photosynthesis and gain mineral nutrients and water from the soil via their roots
- about the reactants and products of photosynthesis, and a word summary for photosynthesis
- about the dependence of almost all life on Earth on the ability of photosynthetic organisms, such as plants and algae, to use sunlight in photosynthesis to build organic molecules that are an essential energy store and to maintain levels of oxygen and carbon dioxide in the atmosphere.

Test yourself on prior knowledge

1. Name the products of photosynthesis.
2. Describe how plant roots are adapted for their function.
3. Explain why almost all life depends on photosynthetic organisms.

Photosynthetic reaction

Photosynthesis is a chemical reaction that occurs in the green chloroplasts of plants. It needs light from the Sun and converts the reactants carbon dioxide and water into glucose and the by-product oxygen. The word equation for photosynthesis is:

\[ \text{light} \rightarrow \text{carbon dioxide and water} \rightarrow \text{glucose and oxygen} \]

The fully balanced symbol equation for photosynthesis is:

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]

This is an oversimplification of photosynthesis. It is actually a series of controlled reactions that you will learn more about beyond GCSE.

Reactants and products

Because it requires light and the green chlorophyll pigment in chloroplasts, photosynthesis mainly occurs in the leaves of plants that face the Sun and possess many chloroplasts. The palisade mesophyll leaf cells have the highest number of chloroplasts and so complete the majority of the photosynthesis.

Gases, including carbon dioxide, are absorbed from the air into spaces between the spongy mesophyll cells of a leaf. Water is absorbed by osmosis into the root hair cells before being transported to the leaves (and rest of the plant) through xylem vessels in transpiration.

Plants complete photosynthesis to produce glucose. They require light to do this, so photosynthesis cannot occur in the dark. Because it requires energy to work, it is an endothermic reaction. These are
Plants produce oxygen as a by-product. They don’t produce it to help animals live. It is handy for animals that they do, however, for without them there would be no oxygen to sustain their life on Earth.

**Photosynthetic algae**

Algae are another group of organisms that can photosynthesise. They are not plants but another large group of uni- and multicellular eukaryotic organisms. Many are microscopic, like the photosynthetic plankton in our oceans, but some, like the giant kelp seaweed, grow as big as many trees. Some algae have green chlorophyll but others have evolved other photosynthetic pigments that are brown and red in colour, giving seaweeds of these colours. It may surprise you that about 70% of the oxygen made each day by photosynthesis actually comes from algae in our oceans and not the plants in our rainforests. Of course this doesn’t mean cutting down trees is less of a problem, but it does mean we should be more careful about water pollution in the future.

**Test yourself**

1. Name the chemical pigment required for photosynthesis to occur.
2. Give the chemical formulae of the products of photosynthesis.
3. Describe why photosynthesis cannot happen in the dark.
4. Describe where on Earth most photosynthesis occurs.

**Rate of photosynthesis**

A limiting factor is anything that reduces the rate of a reaction. If you were making cakes but ran out of eggs, you couldn’t make any more cakes. So eggs would be the limiting factor. There are four limiting factors in photosynthesis:

1. low temperatures
2. shortage of carbon dioxide
3. shortage of light
4. shortage of chlorophyll.

At lower temperatures all chemical reactions occur more slowly because the reactant molecules have less kinetic energy, so they collide less, and therefore react less. Carbon dioxide is a reactant and so the reaction simply slows without it. Light provides the energy necessary for this reaction so reduced levels mean reduced photosynthesis, and no light means no reaction. Plants absorb magnesium by active transport from the soil. They use this to make chlorophyll, so plants with a magnesium deficiency cannot photosynthesise as rapidly as those that have plenty of magnesium. They often have a yellow rather than green appearance. This is called chlorosis.
In this practical you will investigate the effect of light intensity on the rate of photosynthesis using an aquatic organism such as pond weed.

Method
1. Take a piece of pond weed (Cabomba or Elodea) and cut it underwater so that the stalk is cut at a 45° angle.
2. Keeping it under the water, attach a paper clip at the opposite end to the cut stalk and transfer to a boiling tube.
3. Set up a lamp, metre ruler and tank or beaker of water as shown in Figure 9.5.
4 Position the boiling tube with pond weed in it so it is 50 cm away from the light source.
5 Turn off the classroom lights, turn the lamp on and wait for 2 minutes.
6 Ensure that the temperature of the water in the boiling tube with the pond weed remains constant throughout the experiment by monitoring with a thermometer.
7 Count the number of bubbles produced in 1 minute. Repeat this twice more so that a mean rate of bubbles produced can be determined.
8 Move the clamp stand so that it is 40 cm away from the light source and repeat steps 5 and 6.
9 Repeat the experiment for a distance of 30, 20 and 10 cm.

Questions
1 Use the equation 1/distance² to determine the light intensity for each distance used. For example, if the distance were 60 cm the light intensity would be 1/60² or 1/(60 × 60).
2 Plot a line graph of your data with light intensity on the x-axis and mean rate of bubbles on the y-axis.
3 What can you conclude from your data about how light intensity affects photosynthesis?
4 Why was a beaker of water placed between the lamp and the pond weed?
5 Why did you have to wait 2 minutes before counting the number of bubbles?
6 Suggest how you could modify this experiment to measure the rate of oxygen production more accurately.

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Greenhouse crop production

In order to maximise profits, producers need to ensure that plants are grown in the optimum light intensity and temperature and at the correct carbon dioxide concentration. If this is not the case then these could become limiting factors and reduce the yield or quality of the crop.

In a closed greenhouse in winter, with artificial light and no ventilation, the levels of carbon dioxide can drop during the day to 200 parts per million (ppm). The normal atmospheric concentration of carbon dioxide is 370 ppm, which is assumed to give a rate of photosynthesis of 100%. This rate is shown in red on the graph in Figure 9.6.

Questions
1 Use the graph to find the effect on the rate of photosynthesis if carbon dioxide levels are reduced from 370 ppm to 200 ppm.
2 Increased carbon dioxide concentrations have been shown to result in larger lettuce plants with more leaves. Colorado State University found that increasing carbon dioxide levels to 500 ppm resulted in a 27% increase in the mean size of the lettuces.

a) Use your knowledge of photosynthesis to explain why the lettuces were bigger.
b) Use the graph to determine the percentage rate of increase in photosynthesis when concentrations of carbon dioxide were increased from 370 ppm to 500 ppm.
Uses of glucose from photosynthesis

It often helps to think of photosynthesis in terms of where the energy is. The two reactants, carbon dioxide and water, have a relatively small amount of energy within them. The energy found within the two products, glucose and oxygen, is greater. You will have learnt that energy cannot ever be created or destroyed, only converted from one form to another. So how can the products of this reaction have more energy than the reactants? Where does this energy come from?

The answer is energy transferred by the light. This energy is used to power the reaction. It breaks apart the chemical bonds in the reactants and re-forms them with some extra energy stored in the bonds of the products. It is this extra energy that supports almost all life on Earth. When you think like this, it is obvious that photosynthesis can't happen in the dark.

The energy that plants have stored in the formation of glucose during photosynthesis has five general uses. It is:

1. used in respiration
2. converted into insoluble starch and stored
3. converted into fats and oils and stored
4. used to make cellulose cell walls for growth
5. used with nitrate ions absorbed from the soil to make proteins.

As well as these uses, the energy is also transferred along food chains when herbivores eat plants and then are consumed by carnivores. Approximately only 10% of the energy is transferred to the next animal. The rest is used by the organism to live and goes back to the environment as waste substances or heat. Without photosynthesis in plants and algae there would be little animal life on Earth.

Show you can...

Explain whether there is more energy in the reactants or products of photosynthesis.

Test yourself

5. Define the term ‘limiting factor’.
6. Name the limiting factors for photosynthesis.
7. Describe why plants need magnesium.
8. Describe how farmers can increase the rate of photosynthesis of plants inside a greenhouse.
Chapter review questions

1. Name the two reactants in photosynthesis.
2. Name the plant organs in which most photosynthesis occurs.
3. Name the plant cell organelle in which photosynthesis occurs.
4. What is the source of the energy required for photosynthesis to occur?
5. Describe why plants carry out photosynthesis.
6. Explain why there would be almost no life on Earth without plants.
7. Give the word equation for photosynthesis.
8. Name the green chemical that must be present for photosynthesis to occur.
9. Name the plant tissue in which most photosynthesis occurs.
10. Name the plant tissue with the highest concentration of chloroplasts.
11. Name the type of specialised cell in a plant that absorbs the most water.
12. Other than plants, name another type of organism that photosynthesises.
13. Give the chemical formula for glucose.
14. Define the term 'limiting factor'.
15. Name the process by which plants absorb mineral ions from the soil.
16. Name the key metal element in making chlorophyll.
17. Describe the leaves of a plant with a magnesium deficiency.
18. Explain why farmers often grow crops in polytunnels and greenhouses.
19. Give the five uses of glucose formed during photosynthesis.
20. Name the compound produced by plants to strengthen their cell walls.
21. What proportion of energy moves through each stage of a food chain?
22. Explain why photosynthesis is an endothermic reaction.
23. Explain why the rest of the plant, and not just the leaves, requires the glucose made during photosynthesis.
24. Other than green, give the other two colours of photosynthetic pigment present in plants and algae.
25. Give the balanced symbol equation for photosynthesis.
26. Name the four limiting factors in photosynthesis.
27. Explain why less photosynthesis occurs at lower temperatures.
28. Explain why more photosynthesis occurs with more carbon dioxide.
29. Explain why less photosynthesis occurs under lower light conditions.
30. Describe an experiment in which you investigate the effect of light intensity on photosynthesis.
31. Define the term 'yield'.
32. Describe what farmers can do to greenhouses or polytunnels in which they are growing plants to improve their yield.
33. Where is the energy that is taken in by photosynthesis stored after the reaction?
34. Explain how we know there more energy in glucose and oxygen combined than in carbon dioxide and water combined.
35. Name the type of ions absorbed by roots which are used by plants to make proteins.
Practice questions

1 a) Copy and complete the word equation for photosynthesis. [2 marks]

\[ \text{carbon dioxide} + X \rightarrow \text{glucose} + Y \]

b) Describe how the carbon dioxide needed for photosynthesis gets into the plant.

c) Copy and complete the sentences by choosing the correct words from the box.

light root mitochondria respiration chemicals flower chloroplasts haemoglobin chlorophyll ribosome leaf

i) The plant organ that is specialised to carry out photosynthesis is the __________________________. [1 mark]

ii) The energy needed for photosynthesis to occur comes from __________________________. [1 mark]

iii) Energy is absorbed by a green pigment called __________________________. [1 mark]

iv) This green pigment is found in small organelles called __________________________. [1 mark]

2 After a plant had been kept in the dark for 48 hours it was set up as shown in Figure 9.8. After another 24 hours the leaves from inside bags A, B and C were removed and a test was carried out to see if starch was present.

![Figure 9.8](image)

\[ \begin{align*}
&\text{A} \quad \text{B} \quad \text{C} \\
&\text{light} \quad \text{light} \\
&\text{chemical that absorbs carbon dioxide} \\
&\text{vinegar with baking soda to provide carbon dioxide}
\end{align*} \]

a) Copy and complete Table 9.1 to show the likely results of the experiment by placing the letters in the correct column. [2 marks]

<table>
<thead>
<tr>
<th>Starch present</th>
<th>Starch not present</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) i) Which chemical would have been used to test the leaves for starch? [1 mark]

A Biuret solution  
B Benedict’s solution  
C Iodine solution  
D Ethanol solution

ii) What colour would indicate a positive result for starch? [1 mark]

A Purple  
B Blue-black  
C Reddish orange  
D Green

3 A farmer was growing tomatoes in a greenhouse. The graph shows the effect of temperature and concentration of carbon dioxide on the rate of photosynthesis of the tomato plants.

![Figure 9.9](image)

\[ \begin{align*}
&\text{25 °C} \\
&\text{10 °C} \\
&\text{Carbon dioxide concentration in %} \\
&\text{Rate of photosynthesis in arbitrary units}
\end{align*} \]

a) From the graph conclude:

i) the best temperature at which to grow the tomato plants [1 mark]

ii) the best concentration of carbon dioxide to use to grow the tomato plants [1 mark]

iii) the maximum rate of photosynthesis recorded. [1 mark]

b) Apart from temperature and carbon dioxide concentration, what other factor could the farmer change to increase the rate of photosynthesis? [1 mark]

4 Outline a plan to investigate how the rate of photosynthesis in pondweed changed when the intensity of light was changed.

a) Describe how you would do the investigation and the measurements you would take. [6 marks]

b) Describe how you would make it a fair test.
Planning and variables

A variable is a quantity or characteristic. In investigations three types of variable are discussed: independent variables, dependent variables and control variables.

By knowing what the variables are, a clear method can be written that outlines the procedure and the steps taken in order to make it a fair test.

A group of students were planning to investigate the effect of carbon dioxide concentration on the rate of photosynthesis. They decided they would measure the rate of photosynthesis by hole-punching small discs out of spinach leaves, and placing them in a 10 cm$^3$ syringe of sodium hydrogen carbonate solution ($\text{NaHCO}_3$). By pressing on the plunger of the syringe they could increase the pressure. This forced any trapped air out of the spongy mesophyll of the leaf discs and made them sink. Because gas is produced in photosynthesis, the time taken for the leaf discs to rise (inflate again) could be used as a measure of the rate of photosynthesis.

Before they started, the students wrote up their experiment method.

1. Read through the method below and write down any parts where it is not clear how a control variable will be kept constant. Explain how the method could be improved to overcome this.

2. Then write down a clear method to explain how the above experiment could be modified to investigate the effect of temperature on the rate of photosynthesis. Ensure you clearly detail what the variables would be.

Method

1. Wearing eye protection, cut out the spinach leaves using a hole-punch and add these to the syringe by removing the plunger.

2. Add to this one drop of washing-up liquid and replace the plunger.

3. Draw up a 0.5% sodium hydrogen carbonate solution into the syringe.

4. Hold the syringe with the tip pointing upward and expel any air that remains in the syringe by depressing the plunger carefully. Stop before any of the sodium hydrogen carbonate solution comes out.

5. Place a finger over the tip of the syringe and hold firmly in place. Pull back on the plunger and hold for 10–15 seconds to create a partial vacuum inside the syringe. Look to see signs of bubbles escaping the edges of the leaf discs.

6. Release your finger and the plunger at the same time, tap gently on the side of the tube and the leaf discs should start to sink.

7. Repeat steps 5 and 6 until all the leaf discs have sunk.

8. Place the syringe under a lamp and time how long it takes for the first leaf disc to reach the surface.

9. Repeat the experiment using a 0.4, 0.3, 0.2 and 0.1% concentration of sodium hydrogen carbonate solution.

Questions

1. What is the dependent variable in this experiment?

2. What is the independent variable in this experiment?

3. What variables must be controlled in order to make the experiment a fair test?
Every one of the thousands of billions of cells that make up your body is respiring now and will continue to do so. If a cell stops it will die. Respiration is therefore an extremely important reaction. It is one of the seven life processes. Just like you, all other life on our planet undergoes respiration or a chemically similar reaction to release the energy it needs to survive. When we discover life elsewhere in the Universe it will probably do something similar.

This chapter covers specification points 4.4.2.1 to 4.4.2.3 and is called Respiration.

It covers aerobic and anaerobic respiration, response to exercise and metabolism.
Respiration is a chemical reaction that occurs in the mitochondria of your cells. This reaction releases the energy stored in glucose to allow your cells to complete the other six life processes: movement, reproduction, sensitivity, nutrition, excretion, and growth. The word equation for aerobic respiration is:

energy

glucose and oxygen \rightarrow carbon dioxide and water

The fully balanced symbol equation for aerobic respiration is:

\[
C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O
\]

This is an oversimplification of aerobic respiration. It is actually a series of controlled reactions that occur that you will learn more about beyond GCSE.

**Reactants and products**

Plants and algae photosynthesise to store energy in glucose. Respiration releases this energy by reversing the process. Glucose reacts in the presence of oxygen to form carbon dioxide and water.
Aerobic respiration

Unlike photosynthesis, which only occurs in the light, your cells must respire continuously through the day and night. Respiration does not require energy to drive the reaction like photosynthesis does. In fact, respiration releases energy to its surroundings to allow respiring cells to live. This makes it an **exothermic** reaction.

It is easy to remember the reactants by answering these questions:
1. Why do I eat? Answer: To get glucose (and other key nutrients).
2. Why do I breathe? Answer: To get oxygen.

It is easy to remember the products by picturing yourself breathing out on to a cold window. What two substances do you breathe out? Carbon dioxide and water (vapour which condenses on the window).

**TIP**
Aerobic respiration does not mean ‘in the presence of air’, even though it sounds like it does. It means ‘in the presence of oxygen’.

Exo sounds like exit. You leave through an exit, so energy leaves in an exothermic reaction.

**KEY TERM**
**Exothermic reaction** A reaction that gives out energy.

**Show you can...**
Explain why some cells, such as sperm and muscle, contain more mitochondria than others.

**Test yourself**
1. What type of reaction is respiration?
2. Name the type of cellular organelle in which respiration occurs.
3. Define the term ‘aerobic’.
4. Describe the balanced symbol equation for respiration.

**Investigating respiration in invertebrates**

Students used a simple respirometer to investigate how much oxygen is used by different invertebrate species. This is shown in Figure 10.2.

**Questions**

1. **a)** Which gas is produced by both invertebrates during the experiment?
   **b)** What happens to this gas during the experiment?
2. **a)** What happens to the water drops over the course of the experiment in both respirometers?
   **b)** Explain the reason for this movement.
3. Which respirometer gives the most accurate reading? Explain why.
   Note: the grasshopper and cricket were released from the respirometers before they ran out of oxygen, and no insects were harmed during this experiment!

**Figure 10.1** Water is produced during respiration and condenses on windows when you exhale.

**Figure 10.2** The equipment used to investigate how much oxygen is used by different invertebrate species.
Conversion of energy in respiration (and photosynthesis)

So the reactants and products in respiration are the opposite of those in photosynthesis.

Photosynthesis:

\[
\text{light} \quad \text{carbon dioxide and water} \rightarrow \text{glucose and oxygen}
\]

Respiration:

\[
\text{energy} \quad \text{glucose and oxygen} \rightarrow \text{carbon dioxide and water}
\]

However, these two crucial chemical reactions are not simply the opposite of each other when we focus on the flow of energy. Photosynthesis is an endothermic reaction, which requires energy from its surroundings to occur. The arrow on the photosynthesis equation shows energy in. Respiration is an exothermic reaction, which releases energy to its surroundings. The arrow on the respiration equation shows energy out.

These two equations work beautifully together for us and many other organisms on Earth. They show how:

- energy transferred by light (mainly from the Sun) is converted into a chemical store of energy in glucose by photosynthesis
- energy for life processes is released from glucose by respiration.

The energy released from glucose has two main functions. It is converted into:

- thermal energy to keep an organism warm (especially in warm-blooded birds and mammals)
- a chemical store of energy that is available for reactions and processes, such as movement, in an organism.

Heat from respiration

To investigate the heat produced by respiring organisms, a student heated 200 cm$^3$ of a 10% glucose solution to 35 °C and then stirred in 20 g of baker’s yeast (*Saccharomyces cerevisiae*). The mixture was then poured into a thermos flask and a tightly fitting bung with two bore holes was used to stopper the flask. A thermometer was inserted in one of the holes so the temperature could be monitored over the course an hour.

**Questions**

1. Explain why a second hole was needed in the bung.
2. a) Describe how you would expect the temperature readings to vary over the course of an hour.
   b) Explain why this is.
3. Describe a suitable control that could be used in this experiment and explain the purpose of having one.
Anaerobic respiration

Response to exercise

There will be times in your life when you cannot breathe quickly or deeply enough to supply all of your cells with all the oxygen they need to keep on respiring aerobically. This might be the last time you had to run the cross-country at school or when you were last out of breath. At this point your cells, particularly your muscles, start to run out of oxygen. They can only respire **anaerobically**. The word equation for this is:

\[
\begin{align*}
\text{energy (only 5%)} & \\
glucose & \rightarrow \text{lactic acid}
\end{align*}
\]

Reactants and products

Cells respiring anaerobically are missing oxygen and so cannot make carbon dioxide and water. Instead they make an intermediary substance called lactic acid. Many scientists believe that a build-up of lactic acid in a muscle causes cramp. This causes muscle fatigue and stops it contracting so efficiently.

Because the reaction has not been fully completed (because of the lack of oxygen) the total energy released from anaerobic respiration is much less than during aerobic respiration. Only about 5% of the energy (or \( \frac{1}{20} \)) is released. This means that when you are respiring anaerobically, your body is releasing less energy and producing a substance that hurts you (lactic acid). Is it trying to tell you something?!

Paying your oxygen debt

When you have finished exercising vigorously it is likely that you will sit down and relax. We say you have an **oxygen debt** to your body at this point. (You owe it oxygen.) For the next few minutes you will continue to breathe deeply and quickly to replenish the oxygen you have used up. You are repaying your oxygen debt. Your pulse rate will remain high to pump the newly oxygenated blood and glucose as quickly as possible to your muscles for more aerobic respiration.

**KEY TERMS**

- Anaerobic: In the absence of oxygen.
- Oxygen debt: The temporary shortage of oxygen in respiring tissues and organs.
After a few minutes your breathing will return to normal. Now you probably feel tired but not nearly as tired as you did a few minutes ago. This is because this reaction can now happen:

\[
\text{lactic acid + oxygen} \rightarrow \text{carbon dioxide and water}
\]

The lactic acid reacts with the new oxygen in your body to produce carbon dioxide and water. Crucially, this releases the remaining 95% (or \(\frac{19}{20}\)) of the energy that was stored in the lactic acid. This means you no longer have lactic acid and so no longer have cramp. In reality it is a more complicated reaction than shown above, but you only need to know it in this detail at GCSE.

The lactic acid that builds up during anaerobic respiration diffuses from a high concentration in your muscle cells to a low concentration in your blood. By the time it reaches your liver it is at a high concentration in your blood and so diffuses again into the low concentration in your liver. Here it is converted back into glucose by an oxidation reaction. This then diffuses into the blood for use in either aerobic or anaerobic respiration.

**KEY TERM**

**Oxidation** Any reaction in which a substance gives up electrons, as when reacting with oxygen.

▲ Figure 10.6 These sprinters have produced a lot of lactic acid in their muscles during the race. What happens to the lactic acid?

**Test yourself**

9 Give the percentage of energy released in anaerobic respiration compared to that released in aerobic respiration.

10 Where is lactic acid broken down?

11 Describe where the majority of the energy is stored in anaerobic respiration.

12 Define the term ‘anaerobic’.

**Anaerobic respiration in plants and microorganisms**

It is a common misunderstanding that plants only photosynthesise and animals only respire. If plants only photosynthesised they would all be mass-producing glucose but not be able to use this energy to complete the life processes (and so die). Just like each and every one of your cells, every plant cell in every plant on our planet must respire or it will die. So plants photosynthesise during the day, and respire during the day and also the night. Just like animals, plants respire anaerobically when they do not have enough oxygen. This occurs in root cells in waterlogged soils and can cause roots, and eventually the whole plant,
Some microorganisms such as yeast, a single-celled fungus, also respire in this way. The equation for their anaerobic respiration is:

\[
\text{glucose} \rightarrow \text{energy, ethanol and carbon dioxide}
\]

If this reaction happens in yeast cells it is called fermentation. This microorganism and this reaction are economically important in the manufacture of alcoholic drinks. The compound ethanol that is produced is commonly known as alcohol. The percentage alcohol in each drink is the percentage of ethanol in it. Drinks such as vodka and other spirits have about 40% ethanol. Wines usually have about 12% ethanol and beers about 4%.

Yeast is also economically important in the manufacture of bread. If the same reaction is occurring, why does our bread not taste alcoholic? Bread is baked in an oven and so the yeast is killed before it can make too much ethanol. Any that it does make is evaporated away by the heat of the oven.

**KEY TERM**

**Fermentation** The chemical breakdown of glucose into ethanol and carbon dioxide by respiring microorganisms such as yeast.

**KEY TERM**

**Metabolism** The sum of all the chemical reactions that happen in a cell or in your body. These reactions include digestion of food, aerobic and anaerobic respiration which you have just learnt about, and protein synthesis. For plant and algal cells, metabolism also includes photosynthesis. Your metabolism is regulated by your thyroid gland.

These reactions are sped up (catalysed) by enzymes. They use the energy released in respiration.

**Breakdown reactions**

The first type of metabolic reaction makes more, smaller, often less complicated, molecules. These are breakdown reactions. Usually these reactions do not require much energy, if any, from respiration to occur. The following are examples of this type.
Protein breakdown: If you have more protein molecules than your cells need, they are broken down to form amino acids, which diffuse from a high concentration in your cells into the lower concentration in your blood. By the time they reach your liver they are at a high concentration in your blood and diffuse into the low concentration in your liver. Here they are broken down to form urea, which is in turn excreted by your kidneys.

Amino acid breakdown: Amino acids in the liver undergo a breakdown reaction. Here an enzyme removes an amine group, which breaks down the amino acid into urea.

**Synthesis reactions**

The second type of metabolic reaction makes larger, often more complicated, molecules. These reactions require energy released from respiration to occur. The following are examples of this type.

- **Reactions of glucose:** Glucose is produced by plants and algae during photosynthesis. It can then be converted to insoluble starch, which is stored, or converted to cellulose and used for cell walls and growth. In addition, animals can convert glucose into glycogen, which is stored in the liver. This process reduces their blood sugar concentration.

- **Making lipids (fats and oils):** Lipids are made from three molecules of fatty acids and one molecule of glycerol. Lipids are used to make cell membranes and as a chemical store of energy.

- **Protein synthesis:** Glucose and nitrate ions are used to make amino acids. A chain of amino acids when folded into a specific shape is a protein.

**Test yourself**

17 Define the term ‘metabolism’.
18 Where are proteins broken down?
19 Describe an example of a synthesis reaction.
20 Describe an example of a breakdown reaction.
Chapter review questions

1. Explain the difference between respiration and ventilation.
2. Name the reactants in aerobic respiration.
3. Define the term ‘aerobic’.
4. Give the word equation for respiration.
5. Name the process that provides oxygen for respiration.
6. Describe the conditions under which anaerobic respiration occurs.
7. Give the word equation for anaerobic respiration.
8. What are the effects of producing too much lactic acid?
9. Name the process by which oxygen moves into the cells for respiration.
10. Give the word equation for anaerobic respiration in microorganisms.
11. Explain the economic importance of anaerobic respiration in microorganisms.
12. Suggest the approximate percentage of alcohol in beer, wine and spirits.
13. Name the organelle in which respiration occurs.
14. What are the uses of the energy released during respiration?
15. Explain why respiration is an exothermic reaction.
16. Give the proportion of energy released in anaerobic respiration compared with aerobic respiration.
17. Define the term ‘oxygen debt’.
18. Explain why your heart rate and breathing rate increase during exercise.
19. Define the term ‘fermentation’.
20. Define the term ‘metabolism’.
21. Describe an experiment in which you investigate the heat produced by respiring yeast.
22. Explain why energy is not a product of respiration.
23. Explain why photosynthesis and aerobic respiration are not the opposite of each other.
24. Give the balanced symbol equation for aerobic respiration.
25. Explain the flow of energy through photosynthesis and aerobic respiration.
26. Name the main source of energy for the vast majority of the reactions in your cells.
27. Explain what happens when you have paid your oxygen debt to your body.
28. Where is the unreleased energy stored in anaerobic respiration?
29. What happens to the lactic acid produced during anaerobic respiration?
30. Define the term ‘oxidation’.
31. Describe an experiment in which you investigate the oxygen consumption for respiration in two invertebrate species.
Practice questions

1 Respiration occurs in living organisms.
   a) i) What is the purpose of respiration? [1 mark]
      ii) Using your knowledge of the word equation for aerobic respiration, identify which of the following are chemical products. [2 marks]
         A Carbon dioxide C Glucose
         B Energy D Water
      iii) Glucose is a reactant in respiration. Which of the following is the correct chemical formula for glucose? [1 mark]
         A C\textsubscript{12}H\textsubscript{6}O\textsubscript{12} C C\textsubscript{6}H\textsubscript{6}O\textsubscript{12}
         B C\textsubscript{12}H\textsubscript{6}O\textsubscript{6} D C\textsubscript{6}H\textsubscript{12}O\textsubscript{6}
   b) Figure 10.10 shows how a respirometer was set up to investigate aerobic respiration in germinating peas. Apparatus A shows the starting point of the water in the respirometer.
      i) Predict which tube, B or C, would show the direction of water movement if the peas were monitored for 10 minutes. [1 mark]
      ii) Explain the role of the soda lime in this experiment. [2 marks]

2 A student was investigating the effect of exercise on an athlete's body. She collected data on their heart rate before and after exercise. Table 10.1 shows the data collected.

Table 10.1

<table>
<thead>
<tr>
<th></th>
<th>Resting</th>
<th>During exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate in beats per minute</td>
<td>65</td>
<td>125</td>
</tr>
<tr>
<td>Volume of blood pumped out of the heart in each beat in cm\textsuperscript{3}</td>
<td>90</td>
<td>145</td>
</tr>
<tr>
<td>Cardiac output in cm\textsuperscript{3} per minute</td>
<td>5850</td>
<td></td>
</tr>
</tbody>
</table>

   a) By how much did the athlete's heart rate increase during exercise? [1 mark]

   b) Explain why the athlete's heart rate increased. [3 marks]
   c) Calculate the cardiac output in cm\textsuperscript{3} per minute for the athlete during exercise. Show your working. [2 marks]
   d) Give two other changes that occur in the body during exercise. [2 marks]

3 Yeast cells can respire anaerobically. This means they can be grown in anaerobic conditions inside a fermenter.
   a) What does anaerobic mean? [1 mark]
   b) i) Which of the following is the correct word equation for anaerobic respiration in yeast? [1 mark]
         A Glucose \rightarrow \text{lactic acid} + \text{carbon dioxide}
         B Glucose + oxygen \rightarrow \text{lactic acid} + \text{carbon dioxide}
         C Glucose \rightarrow \text{ethanol} + \text{carbon dioxide}
         D Glucose + oxygen \rightarrow \text{ethanol} + \text{carbon dioxide}
   ii) Give one way anaerobic respiration in yeast is different to anaerobic respiration in human cells. [1 mark]
   c) Figure 10.11 shows the changes that occur in a fermenter over the course of 24 hours. Describe how ethanol production changed over the 24-hour period. [2 marks]

4 A woman is taking part in an exercise class. Initially her body cells are carrying out aerobic respiration.
   a) Write a balanced equation for aerobic respiration. [2 marks]
   b) As the exercise becomes more vigorous, her cells switch to anaerobic respiration.
      i) What is produced? [1 mark]
      ii) Explain how the substance produced is broken down after the exercise has finished. [2 marks]

5 Describe the similarities and differences between aerobic and anaerobic respiration in humans. [6 marks]
Means and ranges

Two students were investigating the effect of temperature on respiration in yeast. Terry set up his experiment using the apparatus shown in Figure 10.12a and Afreen as shown in Figure 10.12b.

Both students added the same amount of glucose solution and yeast to their apparatus and covered it using $20\,\text{cm}^3$ of liquid paraffin. They then placed their equipment in a water bath at $20\,\text{°C}$ and left it for 5 minutes. After the 5-minute period, they measured the volume of gas produced in 10 minutes: Terry by counting the number of bubbles and Afreen by recording the movement of the gas syringe. They repeated their experiment five times and then repeated it over a range of temperatures, from 20 to $80\,\text{°C}$.
Both of the students' data shows variation in results. This is to be expected with repeated results. The range of the results is the highest and lowest value recorded for each set of data. The narrower the range, the closer the results are to each other and the more repeatable the data. For Terry's results at 20 °C the range is 345–400.

Questions

1. Calculate the range for Terry’s other temperature results and determine which of his data sets has the most repeatable data.

The more repeatable the data, the more confident you can be that the true value of a measurement lies within the range of your data. To estimate a true value from a range you should calculate a mean. This is done by adding up the repeats and dividing the number by the total number of repeats taken. The result should be rounded to the same number of decimal places or one more than the raw data.

Questions

2. Calculate the means for Terry’s results at 35 °C, 50 °C, 65 °C and 80 °C.

The more repeats taken, the easier it is to spot anomalies. An anomaly is a value that is not in line with the other data and is therefore not likely to be caused by random variation.

Questions

3. Identify any anomalous results in Afreen’s data.

When data can be identified as being anomalous they should be left out of the ranges and means, as they can skew the data and make them less accurate.

Questions

4. Work out the ranges and means for Afreen’s data.
5. What is the trend shown in both students’ data? Can you explain this?
6. Whose equipment allowed them to gather more accurate data? Explain why.
7. Why in both experiments was the yeast and glucose solution left for 5 minutes before the measurements were started?
8. Why in both experiments was the yeast and glucose solution covered in liquid paraffin?
9. What gas were both students collecting, and how could they test it to prove what it is?
In order that you can read this sentence, light must reflect into your eyes from the page. Your eyes really are amazing. They contain millions of receptor cells, which detect different wavelengths of light and start electrical signals. These travel along your nerves in your central nervous system to your brain. Your nervous system is your brain, spinal cord and the network of nerves that spread throughout your body. You have a staggering 45 miles of them!

This chapter covers specification points 4.5.1.1 to 4.5.2.4 and is called The human nervous system.

It covers homeostasis, the structure and function of the nervous system, the brain and the eye, and the control of body temperature.
Homeostasis

There are certain conditions that your body needs to keep stable in order to survive. You need to have enough glucose in your blood for your cells to respire. Not enough would leave you without sufficient energy, and too much would send you into a coma. You need to be warm. Too hot or cold and your enzymes wouldn't be able to control your cellular reactions. You need to have sufficient water. Too little or too much water in your body would kill you. So your body maintains your:

- blood glucose concentration
- body temperature
- water balance.

The maintenance of these three key conditions (and many others) is called **homeostasis**. This is the detection of changes to these conditions and responses to return the body to normal. The definition of homeostasis is the regulation of the internal environment of a cell or organism to maintain optimal conditions for function. These changes are automatic. You do not know that they are occurring. They are described as involuntary.

Many of your body’s systems are involved in maintaining internal conditions. Your nervous system coordinates your voluntary and involuntary actions. It does this by transmitting electrical impulses along your nerves. These are generated by receptors that detect chemical or physical changes in the surrounding environment. They move very quickly along your nerves. As a consequence, homeostatic responses that involve your nervous system happen very quickly.

Other parts of your body produce chemical impulses called hormones. These are proteins and are made during protein synthesis. The hormones are released by glands into your bloodstream. They travel around the blood until they reach their target organ, where they begin causing a change. Because these chemical impulses travel in the blood they are much slower than electrical impulses that travel along nerves.

The electrical impulses that travel along your nerves and the chemical impulses in your blood reach parts of your body called control centres. These include your brain, spinal cord and pancreas, and they process the information and respond accordingly. These centres can respond by releasing a hormone in the case of the glands in your brain or your...
pancreas. They can also send another electrical impulse back along your nerves. These usually end in glands or muscles, which are called effectors because they can bring about a response. For example, the sweat glands in your skin might produce more sweat in response to a high temperature.

**Show you can...**

Explain why maintenance of blood glucose is an example of homeostasis.

**Test yourself**

1. Give an example of homeostasis.
2. Give an example of a control centre.
3. Describe why responses along nerves are faster than hormonal ones.
4. Describe the role of your nervous system.

## Structure and function

An animal’s nervous system controls its voluntary and involuntary actions and is responsible for transmitting and receiving impulses in different parts of its body. In most animals, including humans, it is comprised of the central nervous system (CNS) and the network of nerves that spreads from it throughout your body. The CNS is composed of your brain and spinal cord. Nerves are made from bundles of individual neurones.

**KEY TERM**

Central nervous system (CNS)
The brain and spinal cord.

---

▲ Figure 11.1 This flow diagram shows how the nervous system enables the body to respond to changes.

**Generating electrical impulses**

All messages sent along nerves are electrical. This means they move quickly along them. In longer nerves that have a myelin sheath to insulate the impulse, these speeds can reach 120 metres per second. This is over 250 miles per hour! Think about how fast you move if you put your hand on a hot surface.
These electrical impulses are generated by special cells called receptors and travel to your brain and/or spinal cord. There are many different types of receptor that measure and respond to different stimuli. These are often associated with your sense organs. Table 11.1 shows your senses and the associated stimuli.

### Table 11.1 Your senses, the organs and the stimuli involved.

<table>
<thead>
<tr>
<th>Sense</th>
<th>Organ</th>
<th>Stimuli</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sight</td>
<td>Eyes</td>
<td>Light</td>
</tr>
<tr>
<td>Hearing</td>
<td>Ears</td>
<td>Sound (and position of head)</td>
</tr>
<tr>
<td>Taste</td>
<td>Tongue</td>
<td>Chemicals in food</td>
</tr>
<tr>
<td>Smell</td>
<td>Nose</td>
<td>Chemicals in air</td>
</tr>
<tr>
<td>Touch</td>
<td>Skin</td>
<td>Touch, pressure, temperature, pain and itch</td>
</tr>
</tbody>
</table>

There are tiny hairs in a part of your inner ear called the cochlea. These are the sound receptors that generate electrical impulses that travel to your brain to allow you to hear. Your ears also possess receptors that tell your brain whether you are upright. These impulses help you balance. Your skin is covered with a large number of different receptors. They are not always found in the same number in the same place in your skin. Which parts of your skin are the most sensitive? This is where the most receptors are found. Usually your fingertips and lips have the most receptors, and the soles of your feet and elbows have the least.

### Sensory, relay and motor neurones

Once a receptor has started an electrical impulse it moves along a series of neurones towards your brain and spinal cord. Any neurone that takes an impulse in this direction is called a sensory neurone. Once inside your CNS the electrical impulse is passed along relay neurones. Finally the impulse passes from your brain or spinal cord to your muscles or glands along motor neurones. Your muscles can then contract and relax to help you move in response. Your glands can produce and secrete hormones into your bloodstream. Because muscles and glands both effect a response, we call them effectors. This can be shown in a pathway:

stimulus → receptor → coordinator → effector → response

This can also be shown in more detail:

stimulus → receptor → sensory neurones → relay neurones → motor neurones → effector → response

Remember that the only cells in this that are in your CNS are the relay neurones. The differences in the structures of sensory, relay and motor neurones are shown in Figure 11.3 (overleaf).
Responses

Your receptors detect changes in your environment or your body and send electrical impulses along your sensory neurones to your CNS. Your brain and spinal cord coordinate a suitable response. They then send impulses to your muscles along motor neurones to make you or a part of you move, or they send messages to glands to secrete hormones into your blood.

Synapses

There is not just one sensory neurone that connects each part of your body to your CNS or just one motor neurone that passes the impulse on to your effectors. If there was and this neurone was damaged you would not be able to feel anything in that part of your body or send an impulse back to respond. Instead there is a network of interconnecting sensory neurones that transmit electrical impulses from your receptors to your CNS and a network of motor neurones that send impulses back to your effectors. There is also a network of relay neurones in your CNS.

Neurones in this network do not touch each other. There is a small gap between each of them called a synapse. When an electrical impulse reaches the end of the axon it spreads out into the ends of the cell, which look a little like the roots of a plant. At the tips of these ‘roots’ are special areas that convert the electrical impulse into a chemical signal. These are called chemical neurotransmitters and quickly diffuse across the synapse. On the other side the neurotransmitters meet the dendrites of the next nerve cell. Here they bind to receptors and trigger the start of the electrical impulse, which travels along that neurone until it reaches the next synapse. The neurotransmitters are broken down by enzymes to stop the second neurone from continually sending new electrical impulses. This conversion between electrical impulses and chemical signals happens very quickly.

The reflex arc

Some of your responses are automatic. They happen quickly. An example of this might be moving your hand away from a hot radiator you have just touched by mistake. Others include regulating your heart rate and controlling the amount of light that enters your eyes. These responses do not require your brain to make a decision. They are called reflex responses.
Because reflex responses happen quickly they often occur to stop you damaging your body by mistake. Remember how quickly you move your hand from a hot radiator! Just as described before, the electrical impulse is first generated by a receptor. In this case, this is a pain receptor in the skin of your hand. The impulse travels quickly through a series of sensory neurones and their synapses to your spinal cord. Here relay neurones take over the impulse. However, this impulse does not travel immediately to your brain. Your spinal cord is able to send the impulse back along motor neurones to your muscles. These then quickly contract, moving your hand from the radiator. This is called a reflex arc.

**TIP**
It is important that you can explain how the structure of neurones in a reflex arc relates to their function.

**KEY TERM**

**Reflex arc** The route of an electrical impulse that avoids the brain to save time and so helps prevent damage to your body.

![Figure 11.5 A reflex arc. Note the route.](image)

![Figure 11.6 The neurones involved in a reflex arc.](image)

Other responses require a decision to be made. Think about how much longer a decision would take to answer the question ‘How comfortable is your new school uniform?’ compared with moving your hand away from a hot radiator. Decisions like this are not automatic. We call them conscious decisions. When you make conscious decisions the electrical impulse travels along relay neurones to your brain before moving back along motor neurones to your muscles (and glands).

**Plan and carry out an investigation into the effect of a factor on human reaction time**

In this experiment you test the reaction time of yourself and a partner using visual and auditory cues.

**Method**

1. In pairs decide who will have their reaction time tested and who will be the tester.
2. The tester should hold two 30 cm rulers vertically at the end near the 30 cm mark, one in each hand.
3. The other person places their index finger and thumb of each hand either side of the 0 cm marks, holding them as wide as possible ready to catch a ruler when one falls.

**TIP**
Be careful when you talk about changing reaction times. Reducing your reaction time means that your reaction is faster.
Figure 11.7 How to test your partner’s reaction time.

4 Without warning, the tester lets go of one of the rulers and the other student tries catch the ruler as soon as possible.
5 Record the distance travelled by measuring where the ruler was caught just above the student’s first finger.
6 Repeat this two more times, ensuring that the ruler is always dropped at random times, and then calculate a mean (charts are available to convert centimetres to seconds).
7 Repeat the process, but this time the student being tested should close their eyes and the tester should say ‘left’ or ‘right’ as they drop the corresponding ruler. Again do three repeats so that a mean can be determined.
8 Swap over and repeat the whole experiment.

Questions
1 Who had the quickest reaction time?
2 How repeatable and reproducible were your data?
3 Were your reaction times quicker with visual or auditory clues?
4 What is the stimulus in both experiments?
5 What is the response?
6 Draw a reflex arc to outline the route the nervous impulse takes when you see the ruler falling.
7 Explain how the experiment could be adapted to measure the effect of caffeine on reaction time.

Test yourself
5 Name the two parts of the central nervous system.
6 Name the two types of effector.
7 Describe what happens when an electrical impulse reaches the end of a neurone.

Show you can...
Explain how the reflex arc protects you from damage when you touch a hot radiator.
The brain

The brain is the organ that is at the centre of the CNS of almost all animals. Some, such as jellyfish and starfish, do not have a brain, but they do have areas with similar nerve tissue. It is usually found in an organism’s head, close to the major organs for senses. Your brain is very close to your eyes, ears, nose and mouth. In vertebrates it is surrounded by a skull for protection.

Structure of the brain

The brain is made up of billions of neurones. Scientists think there may be between \(10^{14}\) (one million billion) and \(5 \times 10^{14}\) (five million billion) synapses in your brain. The brain is divided into distinct regions, shown in Figure 11.8.

The cerebral cortex is the outer part of the largest bit of your brain, which is called the cerebrum. This is estimated to have between 19 and 23 billion neurones. The cerebral cortex is divided into two sections, the left and the right. It plays a major role in our memories, our consciousness, our intelligence and our ability to use language. It can be divided into four further regions, as shown in Figure 11.9.

The total number of neurones in the cerebral cortex of animals can be compared. Chimpanzees have around 5.5 billion and elephants have 11 billion. Recently for the first time an animal has been found with more neurones in its cerebral cortex than humans have – a species of dolphin has over 37 billion!

A second part of your brain is called the cerebellum. This is smaller than the cerebral cortex and is found below it closer to your spinal cord. This part controls and coordinates the movements of your muscles. It receives impulses from your spinal cord and other parts of your brain to do this.
A third part of your brain is called the **medulla oblongata**. This is often shortened to ‘medulla’, but this is also the name of part of your kidney, so don’t get confused. The medulla oblongata is found at
the very top of your spinal cord. It controls lots of your unconscious
(automatic or involuntary) activities. These include the rate at which
your heart beats and you breathe, as well as other things such as
vomiting.

### Studying the brain and nervous system

The study of the nervous system is called neuroscience, and those that
study it are called neuroscientists. This first began in ancient Egypt but
until relatively recently did not advance as quickly as some other areas
of medical research. Now neuroscientists understand more about the
biochemistry of the brain and are able to use computers and medical
equipment for research.

Drilling holes in a patient’s skull, called trepanning, was thought to
cure mental disorders in many early cultures throughout the world. In
fact, Ancient Greek physician Hippocrates (460–370 BC) was probably
the first person to believe that senses and intelligence were related
to the brain. Previously people thought the heart was the source of
consciousness.

The work of French surgeon Paul Broca (1824–1880) helped us better
understand the structure of the brain and how it works. He is best
known for his work on a part of the frontal lobe of the cerebral cortex,
now named Broca’s area after him. He found that patients with speech
problems had lesions (abnormal growths) on this part of their brain.
This proved for the first time that different parts of the brain have
different functions.

More recent study has also focused upon patients with brain damage.
Parts of their brain have been electronically stimulated to start
neurones sending impulses. These impulses are then looked at using a
magnetic resonance imaging (MRI) scanner.

### Brain and behaviour

Almost all animals can change their behaviour as a result of their
experiences. Your behaviour is determined by your brain function.
So scientists believe that changes in behaviour result from changes
in the brain. Until recently how these experiences and behaviours
changed the brain of an organism were unknown. Neuroscientists
have recently discovered that small changes occur in how effective
synapses are. Your working memory is used when you are currently
engaged in a task or activity. As you read this book you are using it.
This is thought to be as a result of a small group of neurones that
keep repetitively sending the same impulses to each other. Longer-
term memories are thought to be caused in a similar way but most
likely in the hippocampus (another part of the brain). Facts and
relationships between things are again probably stored in a similar
way but in your cerebral cortex.
The human nervous system

Show you can...

Explain why your brain is located where it is.

Test yourself

8 Name the part of your brain that controls the movement of your muscles.
9 Which other animals have a large brain to body size?
10 Describe the function of your temporal lobe.
11 Describe the results of Broca’s work on the frontal lobe.

The eye

TIP

It is important that you remember how the eye evolved when you revise evolution in Chapter 15.

The eye is the organ of vision. It allows animals to detect light and convert it into electrical impulses that are transferred along nerves. There are at least 10 different types of eye. Perhaps the most common, other than the mammalian eyes we have, are the compound eyes of insects. The simplest types of eye belong to microorganisms. These only tell the organisms whether it is light or dark. In contrast, your eyes see about 10 million different colours!

Structure of the eye

The structure of the mammalian eye is shown in Figure 11.14 and the functions of each of its parts are given in Table 11.2 (overleaf).

Even with this new understanding of structure and function, much of the brain remains a mystery. As a result of its complexity and how delicate it is, investigating and treating brain disorders is a very difficult process.
Table 11.2 The parts of the mammalian eye and their functions.

<table>
<thead>
<tr>
<th>Part</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cornea</td>
<td>The transparent part of your eye that covers the iris and pupil. It refracts light through the pupil.</td>
</tr>
<tr>
<td>Lens</td>
<td>The biconvex structure that sits behind your pupil. It further refracts light to be focused on your retina. Its shape is changed in a process called accommodation when your look at near and far objects.</td>
</tr>
<tr>
<td>Iris</td>
<td>The coloured muscle that surrounds your pupil. It controls the size of the pupil by relaxing and contracting to let more or less light in.</td>
</tr>
<tr>
<td>Ciliary body</td>
<td>A structure made of muscles called ciliary muscles, which can contract and relax to change the shape of your lens during accommodation.</td>
</tr>
<tr>
<td>Choroid</td>
<td>The layer of your eye found between the retina and the sclera. It provides oxygen and nourishment to the cells of the retina.</td>
</tr>
<tr>
<td>Retina</td>
<td>The layer of receptors found inside your eye. It contains two types of light-sensitive cell called rods and cones.</td>
</tr>
<tr>
<td>Fovea</td>
<td>A specific part of the retina that is responsible for your sharpest vision. About half of the neurones that leave your eye come from this point alone.</td>
</tr>
<tr>
<td>Sclera</td>
<td>The white of your eye. It is the outer layer that protects the rest of your eye. In many other mammals it is not white and so is not as easy to distinguish from the iris.</td>
</tr>
<tr>
<td>Optic nerve</td>
<td>The nerve made from neurones that connect your eyes to your brain. Electrical impulses pass from the eyes to the brain to let you see.</td>
</tr>
</tbody>
</table>

Your retina is the part of your eye in which the light-sensitive cells are found. There are two types called rods and cones. Each eye has around seven million cones and between 75 and 150 million rods. Both types of cell work in a similar way to send electrical impulses to your brain. Cones require bright light to work properly. They allow us to see in colour. Rods work in much lower light intensities. When it is dawn or dusk you are probably only seeing using your rods. At these times colours seem less vivid. This is because there is not enough light for your cones to work properly.

**Accommodation**

As described in Table 11.2 and shown in Figure 11.15, the lenses in your eyes can change shape. This is to allow you to focus on objects that are close and also far away. The ciliary muscles in the ciliary body surround each of your lenses. When you look at near objects these muscles contract, which makes your lens more convex. This means your lens becomes shorter and fatter so you can focus on the near object. When you then look at an object that is further away your ciliary muscles relax. This means your lens becomes longer and thinner. You are then able to focus on objects that are further away. This is called the accommodation reflex and is an automatic one.
KEY TERMS

Hyperopia A medical condition called long-sightedness in which people cannot clearly see objects close to them.

Myopia A medical condition called short-sightedness in which people cannot clearly see objects far away.

Activity

Near- and far-points
Outstretch one of your arms and point one finger. Focus on the end of it and slowly bring it towards your nose. There will come a point when you can no longer focus on it. This is the shortest distance at which your cornea and lens can focus the image on your retina. This is called your near-point. Humans have a far-point of infinity. This means we can focus on objects that are millions of miles away.

Long- and short-sightedness
Some people are unable to correctly focus light on their retina. This is called long-sightedness, or hyperopia, if you cannot see objects that are close to you. This may be because your eyeball is too short, your cornea is not curved enough or your lens is not thick enough. In addition, the development of some medical conditions such as diabetes can cause hyperopia.

It is called short-sightedness, or myopia, if you cannot see objects that are far from you. Most babies are born a little long-sighted because their eyes continue to grow to reach their full size. This is usually at about 8 years old. As you get older your eyes find accommodation more difficult and things that are closer become more blurred. Many older people wear reading glasses to help with this.

Hyperopia and myopia have been treated by using corrective lenses as spectacles, or eye glasses, for many years. These help by refracting the light before it enters your eyes. Different people have different eye prescriptions depending upon the extent to which the refraction must occur before it enters their eyes. In recent years more people have used contact lenses to do the same thing. Instead of sitting in front of the eye in a glasses frame, contact lenses are placed on the front of the eye, touching the cornea. Many people prefer to use contact lenses so that it doesn’t look as if they have problems with their eyes. As with eye glasses, contact lenses come in different prescriptions depending upon how far the light needs to be refracted before it enters the person’s eye. Additionally in recent years laser surgery has been used to change the shape of the cornea and replacement lenses have been inserted into patients’ eyes. Both of these techniques also alter the refraction of the light as it enters the eye. These are permanent solutions to accommodation problems.

Test yourself

12 What is the function of the optic nerve?
13 Give the scientific name for long-sightedness.
14 Describe the shape of your lens when you are looking at a distant object.
15 Describe how long-sightedness is treated.
You, like all mammals and birds, are able to regulate your body temperature. This means that your body will make you hotter when you are cold and cooler when you are hot. Because this is an example of your body automatically returning to a normal state, it is an example of homeostasis. Animals that can do this are described as warm-blooded. Those that can’t, like reptiles, are described as cold-blooded. Reptiles such as lizards are often seen lying in the sunshine on hot rocks or sand in the mornings to warm up because their bodies are not able to regulate their temperature internally.

Your body is designed to function most effectively between 36.5 and 37.5 °C. This is the optimum temperature for most of your enzymes. A section of your brain called the thermoregulatory centre controls your body temperature. Your brain has temperature sensors called receptors, which monitor the temperature of the blood flowing through it, and it combines this information with those receptors that cover your skin. Receptors communicate with your thermoregulatory centre via electrical impulses sent along your nerves. Your thermoregulatory centre then coordinates a return towards normal temperature using three different mechanisms: using your sweat glands, using your skeletal muscles and by controlling the blood that reaches the surface of your skin.

**Sweating**

When you become too hot, sweat glands in your body start to produce sweat. Parts of your body such as your underarms, palms and feet have more sweat glands and so produce more sweat. Your body can produce a maximum of several litres per hour. Doing so means you must replace this volume of liquid by drinking. Sweat is mainly water but does contain some salts and other compounds such as urea. Sweat evaporates from your skin and in doing so transfers away heat energy. This cools you. Figure 11.18 shows cross-sections through your skin. Part (b) of the diagram shows a sweat gland producing sweat on a hot day.

**TIP**

Lick the back of one of your hands. Now blow on this hand and your other dry hand to compare. What do you notice?
● **Shivering**

When you become too cold you start to shiver. This is an involuntary movement. You have no control over it. It is caused by your skeletal muscles (those connected to your skeleton) quickly contracting and relaxing. Your muscles do this to generate heat to warm you up. They have to use glucose in respiration to do this, and so you cannot shiver for long periods of time without becoming very tired.

● **Vasoconstriction and vasodilation**

As well as producing sweat, your skin helps control your body temperature in a second way by regulating the volume of blood that reaches its surface. Your blood is relatively warm. When more of it is allowed to reach the surface of your skin some of its heat is lost by convection, conduction and radiation. This cools you down. This process is called **vasodilation**. The arteriole muscles relax to increase their size (dilate). Look back at Figure 11.18(b), which is a cross-section through the skin. It shows how dilated arterioles have more blood in them which can flow in the capillaries near the surface of the skin.

Picture yourself exercising on a hot day. Your skin will probably appear redder. We usually call this looking flushed. This is the increase of blood towards the surface of your skin. The reverse occurs when you are too cold. Your body restricts the flow of warm blood to the surface of your skin. This is called **vasoconstriction**. The arteriole muscles contract to decrease their size (constrict) and so less blood can flow into the capillaries near the surface of the skin.

---

### Investigating the effects of sweating

**Method**

1. Wrap a 250 cm$^3$ conical flask with two sheets of dry paper towel or a dry flannel and hold this in place with elastic bands.
2. Fill the conical flask with 200 cm$^3$ of water at 80°C.
3. Place a bung with a single bore hole in the top of the conical flask and insert a thermometer, ensuring it is measuring the temperature of the water.
4. Record the temperature of the water every minute for the next 10 minutes.
5. Repeat the practical using paper towels or a flannel that has been soaked in cold water and wrung out.

**Questions**

1. Record the data in an appropriate table.
2. Plot a line graph of the results with time in minutes on the x-axis and temperature in °C on the y-axis, ensuring you identify the two lines.
3. What can you conclude from the experiment, and how can you link this to the role of sweating in the human body?
Now picture yourself when you are too cold. You will probably have pale skin and perhaps your lips will be tinged a shade of blue. This is because of the decrease in blood flow near the surface of your skin. The blood is being retained in the core of your body to keep your vital organs as warm as possible for as long as possible.

**Blushing**

When we are hot we have red cheeks because of vasodilation. This is not the same as blushing when we are embarrassed, which is an emotional response to a stressful situation. Scientists are still not sure why this happens.

**Temperature receptors**

In the brain detect a decrease in blood temperature.

Temperature receptors in the skin detect a decrease in skin temperature.

Impulses are sent along neurones to the thermoregulatory centre of the brain.

The thermoregulatory centre sends impulses to skeletal and arteriole muscles.

Arteriole muscles contract to reduce blood flow to skin capillaries.

Skeletal muscles cause shivering.

▲ Figure 11.20 The thermoregulatory centre uses information about the blood and skin temperatures to maintain our body temperature at or near optimum

**Hypothermia and hyperthermia**

When your temperature is increased a little to between 37.5 and 38.5 °C you have a fever. This is often caused by an immune response to infection from a pathogen. When we become so hot that we overcome all the cooling effects our body tries, or these fail, we can develop hyperthermia. This occurs above 38.5 °C. This most frequently happens during heat stroke and during allergic reactions to drugs. Headaches, nausea and vomiting are symptoms. If this continues organ failure will occur, followed by death.

When your temperature falls below 35 °C you develop hypothermia. As this point you will be shivering and often mentally confused. Your ability to regulate your temperature has failed or cannot keep up with the cold temperatures. Oddly, people who are severely hypothermic may have an urge take off their clothes. Hypothermia also causes organs to fail and is followed by death.

**Test yourself**

16 Which classes of vertebrates can regulate their temperature?

17 Which muscles contract when you shiver?

18 Explain why you sweat.
Chapter review questions

1. Name the two parts of the central nervous system.
2. Describe what nerve cells are.
3. Name five senses.
4. Explain how reflex responses are different from voluntary responses.
5. Give an example of a reflex response.
7. Besides water, what else is present in sweat?
8. Name the parts of your body that are most likely to sweat.
9. Explain why you shiver.
10. Describe an experiment in which you investigate the effects of caffeine on reaction time.
11. What types of receptor are present in your eyes?
12. In which direction do sensory neurones send electrical impulses?
13. Where in your body would you find relay neurones?
14. Name the organs or tissues that are found at the end of motor neurones.
15. Describe the pathway of a response.
16. Define the term ‘synapse’.
17. Name the chemicals that move across a synapse.
18. Explain why the nerves do not carry reflex responses to the brain.
19. What are the three main regions of the brain?
20. Describe the function of the iris in the eye.
21. Describe the function of the retina in the eye.
22. Explain how hyperopia and myopia are treated.
23. What is the optimum temperature for your enzymes to work at?
24. Define the term ‘vasoconstriction’.
25. Define the term ‘vasodilation’.
26. What colour might you expect your face to be if your blood vessels are undergoing vasoconstriction?
27. Describe an experiment in which you investigate the effects of sweating.
28. Explain how chemical neurotransmitters work in a synapse.
29. Explain how a reflex arc works.
30. Describe the function of the cerebral cortex.
31. Explain the similarities and differences between the way in which rods and cones work.
32. Explain the process of accommodation when you look at an object that is far away.
33. Explain the process of accommodation when you look at an object that is close to you.
34. Define the terms ‘hyperopia’ and ‘myopia’.
Practice questions

1 a) Using the words below, put the stages of a reflex action into the correct sequence. [4 marks]
   effectors stimulus response coordinator receptor

   b) During a reflex action, as shown in Figure 11.21, the impulse travels along different types of neurones. Name the type of neurone represented by:

   i) Neurone A [1 mark]
   ii) Neurone B [1 mark]

   c) i) On Figure 11.21, X shows a gap between two neurones. What is the term for this gap? [1 mark]
       A Synapse    B Axon    C Dendrite    D Myelin

   ii) Explain how a message is transmitted across such gaps. [3 marks]

   d) During a reflex action the impulse travels approximately 1.5 m at a speed of 120 metres per second. How long would it take in seconds to respond? Show your working. [2 marks]

   e) Name a substance that can slow your reaction speed. [1 mark]

2 a) Figure 11.22 shows two eyes focused on different objects. Which object, A, B or C, is each eye focused on?

   i) Eye 1 [1 mark]
   ii) Eye 2 [1 mark]

   b) What is it called when someone cannot focus on near objects correctly? [1 mark]

   A B C

3 A functional MRI scan was carried out to examine the activity of the brain during four different activities.

   vision    speech    movement

   a) Name the part of the brain involved in carrying out all the activities seen in Figure 11.23, along with memory, intelligence and conscious thought. [1 mark]

   b) i) Use the evidence from Figure 11.23 to explain how you know that different regions of the brain are responsible for different actions. [1 mark]

   ii) Suggest why more than one region of the brain is active during writing. [1 mark]

4 Mammals and birds use homeostasis to regulate their body temperature.

   a) Describe what the term ‘homeostasis’ means. [2 marks]

   b) If your body temperature changes, your body responds to bring your temperature back to normal.

   i) What is the term used to describe this type of process? [1 mark]

   ii) Copy and complete the table to show the different ways the body can respond. [2 marks]

<table>
<thead>
<tr>
<th>Body temperature too low</th>
<th>Body temperature too high</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vasodilation</td>
</tr>
<tr>
<td></td>
<td>Shivering</td>
</tr>
</tbody>
</table>

   iii) Explain how vasodilation can reduce the body temperature. [2 marks]

5 Scientists are trying to show the effects of alcohol on human reaction time.

   Describe a method that involves dropping a ruler that scientists could safely use in a laboratory setting to investigate this.

   You should include:

   a) what they would measure [6 marks]

   b) variables they would control.
Accuracy and precision

As you have learnt, most people think of the human body’s temperature as being 37 °C. However, the normal range is between 36.5 and 37.5 °C. Temperatures outside this range can lead to medical problems. Hypothermia is when core body temperature falls too low. When core body temperature begins to fall, people become drowsy; if body temperature continues to fall, a person can become unconscious and die from hypothermia. If the core body temperature becomes too high, enzymes will denature causing cellular processes to stop. This is called hyperthermia and can quickly cause death.

Thermometers are used to measure core body temperature. Body temperature can be measured in many locations such as the mouth, ear, armpit, rectum and forehead. It is important that the thermometer takes both precise and accurate readings in order to give correct information about a person’s body temperature.

The terms ‘precise’ and ‘accurate’ are often used incorrectly or to mean the same thing. However, there are important differences. An accurate reading is one that is close to the true value (the actual value), whereas precise readings are measurements that are close to each other and show little spread about the mean. These two terms are not interchangeable. You can have precise readings that are not accurate, and accurate readings that are not precise.

The data in Table 11.3 show the readings taken from three thermometers measuring the temperature of a thermostatically controlled water bath. The performance of the thermometers is being measured against a clinical (medical) thermometer, which is giving a reading considered to be the true value.

Table 11.3 Temperature of a thermostatically controlled water bath.

<table>
<thead>
<tr>
<th>Thermometer</th>
<th>Temperature reading in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Clinical</td>
<td>51.0</td>
</tr>
<tr>
<td>1</td>
<td>51.2</td>
</tr>
<tr>
<td>2</td>
<td>48.0</td>
</tr>
<tr>
<td>3</td>
<td>51.4</td>
</tr>
</tbody>
</table>

Questions

1. What are the most accurate and least accurate readings for each thermometer?
2. Work out the mean temperature readings for each thermometer and use this to decide which thermometer is the most accurate.
3. Why does it matter if a thermometer is inaccurate?
4. Which location in the body do you think would give the most accurate reading for core body temperature?
5. Which thermometer produces the most precise readings? Explain your choice.
6. Which of the above thermometers do you think should be used? Explain your choice.
7. Why do we say that the clinical thermometer ‘gives a value considered to be the true value’, rather than it ‘takes the true value’?
12 Hormonal coordination in humans

Puberty involves a lot of changes in your body. It can also affect your emotions and behaviour. These drastic changes in your body mean you have reached sexual maturity and are now able to have children. But why does this happen and what causes it? The answer is the release of hormones from your glands. These are like chemical messages, which travel around your bloodstream telling bits of your body what to do at certain times.

This chapter covers specification points 4.5.3.1 to 4.5.3.7 and is called Hormonal coordination in humans.

It covers homeostasis, the human endocrine system, hormones in human reproduction, contraception, hormones in infertility treatment and negative feedback.
The endocrine system is a group of glands that secrete hormones directly into the blood. Hormones are proteins that are made during protein synthesis. Proteins are large chemical molecules. Hormones travel in the blood until they reach their target organ. Here they effect a change. Examples of hormones, their target organs and their effects are given in Table 12.1, and Figure 12.1 on the next page shows the locations of these glands. Because hormones travel in the blood, their effects are usually slower than impulses that travel along your nerves as a part of your nervous system. However, the effects of hormones are usually longer lasting than impulses along nerves.

Table 12.1 Common examples of hormones and their functions.

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Produced</th>
<th>Target organ</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADH</td>
<td>Pituitary gland</td>
<td>Kidney</td>
<td>Controls the concentration of water in urine</td>
</tr>
<tr>
<td>TSH (thyroid-stimulating hormone)</td>
<td>Pituitary gland</td>
<td>Thyroid</td>
<td>Controls the release of hormones from your thyroid gland</td>
</tr>
<tr>
<td>Adrenaline</td>
<td>Adrenal gland</td>
<td>Heart (and other vital organs)</td>
<td>Prepares the body to fight or run away (flight)</td>
</tr>
<tr>
<td>Insulin and glucagon</td>
<td>Pancreas</td>
<td>Liver</td>
<td>Insulin increases and glucagon decreases the conversion of blood glucose to glycogen</td>
</tr>
<tr>
<td>Thyroid hormones (e.g. thyroxine)</td>
<td>Thyroid</td>
<td>Various</td>
<td>Control how quickly you use energy, make proteins and how sensitive your organs are to other hormones</td>
</tr>
<tr>
<td>Oestrogen</td>
<td>Ovaries</td>
<td>Reproductive organs</td>
<td>Controls puberty and the menstrual cycle</td>
</tr>
<tr>
<td>Testosterone</td>
<td>Testes</td>
<td>Reproductive organs</td>
<td>Controls puberty</td>
</tr>
</tbody>
</table>
The pituitary gland in the brain is your ‘master gland’. It is found just below a part of your brain called the hypothalamus. This section of your brain links the impulses that come along nerves in your nervous system to your endocrine system. Your pituitary gland is about the size of a pea. It secretes hormones that help control growth and blood pressure, as well as partly controlling functions of the ovaries or testes, pregnancy, childbirth and the kidneys. Your pituitary gland releases hormones that have other glands as their target organs. Thus your pituitary gland releases hormones that ‘turn on’ other glands. An example of this is the thyroid gland. This controls how quickly your body uses energy and makes proteins and how sensitive it is to other hormones.

Control of blood glucose concentration

The purpose of your digestive system is to break down large lumps of food into molecules small enough to be absorbed into your blood. Carbohydrase enzymes break down carbohydrates into sugars, which are absorbed through villi into your bloodstream. Your pancreas monitors and controls the amount of blood sugar (glucose) that remains in your blood. Too little and your cells cannot respire, and too much and you become comatose. Because it involves your body automatically returning to a normal state, control of blood glucose is an example of homeostasis.

Many people eat three meals a day. So there will be three times when lots of glucose from their food rushes into their bloodstream. Just before meals there are times when your blood glucose is likely to be low because your cells have been respiring. So your body, and that of all mammals, has evolved a way to store excess glucose after a meal and release it when your body needs it.
Hormonal coordination in humans

Insulin
A hormone called insulin helps to control the concentration of blood glucose. Two organs, the pancreas and liver, are also involved. When your blood glucose is too high, the pancreas detects this and produces insulin, which is released into the bloodstream and reaches its target organ, the liver. The liver then starts to turn the excess glucose into an insoluble larger molecule called glycogen. The formation of glycogen also occurs in your muscles. Its formation reduces your blood glucose concentrations back to normal.

Glucagon
If your blood glucose is too low, your pancreas produces a second hormone called glucagon. This travels in your blood to your liver and muscles, where it converts the insoluble glycogen back into glucose. This is released into your blood to return your blood glucose concentrations to normal. Like all examples of homeostasis, this two-way process is constantly happening all the time in your body.

This is an example of negative feedback control. Here your body has detected a change (high or low blood glucose) and made an adjustment to return it back to normal. All examples of homeostasis involve negative feedback.

Diabetes
Diabetes is a non-communicable disease. People with diabetes cannot easily control their blood glucose levels. There are approximately three million people with diabetes in the UK, and this figure is rising. Some people develop the disorder early in life, while others develop it later, usually as a result of an unhealthy lifestyle. Regardless of the way a person develops diabetes, the symptoms are similar. Because there are two different ways in which diabetes develops there are two different names for it.
Type 1 diabetes

The causes of type 1 diabetes are unknown. About 10% of the total number of diabetic people in the UK have type 1 diabetes. It usually develops in children or young adults when the insulin-producing cells in the pancreas are destroyed. This happens because the sufferer’s immune system mistakenly makes antibodies to attack and destroy these cells. Without these cells the blood glucose concentration of diabetic people can quickly and easily rise to harmful levels, which may become fatal.

People with type 1 diabetes usually inject insulin to help reduce their blood glucose. They can also help do this by reducing the sugar in their diet and exercising regularly. Reducing sugar intake means they need to inject less insulin, and exercise increases the amount of glucose that is used by their muscle cells for respiration. Often diabetic people test their blood glucose several hours after a meal. If they have a high blood glucose concentration they will need to inject a greater volume of insulin.

It is important that type 1 diabetes is diagnosed as early as possible. There is currently no cure, so injecting insulin, eating carefully and exercising manage the symptoms of the disorder without treating them. Some diabetic people have a small pump (about the size of a pack of cards) worn on the outside of the body. It is connected by a short tube and needle (cannula) to a layer of fat that is found just below the skin. It allows the user to regulate the amount of insulin in their blood without daily injection.

Type 2 diabetes

Type 2 diabetes usually develops later in life. Its cause is different from that of type 1 diabetes. People with type 2 diabetes cannot produce enough insulin or, if they can, their liver and muscle cells won’t respond to it. This prevents the conversion of glucose into glycogen and blood glucose concentrations remain high. People who may be developing type 2 diabetes usually feel thirsty, pass urine more often and frequently feel tired. Because these symptoms develop slowly, some people are not aware that they have, or are developing, diabetes.

The number of cases of type 2 diabetes is rising. This is partly because the number of older people is increasing as people are generally living longer. People who do not exercise regularly, have an unhealthy diet (often high in sugar) and are obese are more likely to develop type 2 diabetes. Obesity is an important risk factor for this disorder.

As for type 1, there is no cure for type 2 diabetes. People with this disorder control their blood glucose concentrations by eating a balanced, healthy diet and by exercising regularly. Because the liver and muscle cells of many people with type 2 diabetes do not respond to insulin, injecting insulin is not usually a treatment.
Managing diabetes

Diabetes is a common medical condition and the number of people that have the disorder is increasing. It does have serious medical effects on some people, but many are able to lead relatively normal lives. In fact, some very successful people are diabetic. These include actors Tom Hanks and Halle Berry, as well as Olympic rower Sir Steven Redgrave. He has had type 1 diabetes since 1997 but won five gold medals in five different and successive Olympic Games (from 1984 to 2000). This makes him one of the most successful athletes of all time.

Extension

The discovery and manufacture of insulin

Insulin was discovered by Canadian scientist and doctor Fredrick Banting (1891–1941) and American-Canadian medical scientist Charles Best (1899–1978). Only Banting was awarded the Nobel Prize for this achievement. He thought Best should have been awarded it as well, so he shared half of his prize money with his colleague. Their methods may be viewed now as cruel and out of date, but their work has improved the lives of many people with diabetes ever since.

Banting and Best used dogs in their experiments. First they tied shut the tube that excretes insulin from the pancreas of a dog. They monitored the dog’s increasing blood glucose concentrations over the next 8 weeks and concluded that this organ had something to do with controlling blood glucose concentration. They then operated to remove the pancreas from this dog and a second one. They mashed up the
Maintaining water and nitrogen balance in the body

The cytoplasm of your cells is mainly made from water and crucial chemical reactions such as respiration and protein synthesis occur here. On some occasions you will have less water in your body than normal. Perhaps you are exercising on a hot day. At other times, such as just after a large drink, you will have more. It is crucial that your body is able to regulate the volume of water in your cells so that you don’t have too much or too little and become dehydrated. Your cells will not function properly if they gain or lose too much water.

Explain the differences between type 1 and type 2 diabetes, including their causes and treatments.

Test yourself

5 Which type of diabetes is treated using insulin?
6 Name the organ in which insulin is produced.
7 Describe why insulin produced in bacteria is safer than using pig insulin.
8 Describe how blood sugar concentrations are increased.

Maintaining water and nitrogen balance in the body

You lose water from your body when you urinate, sweat and breathe out (as water vapour). You have no control over this water loss. Ions and urea are also lost with this water in your urine and sweat. Urea is the result of excess protein that your body has broken down to excrete. Your body is able to control how much water is lost by controlling the amount of water in your urine and its volume. If you do not have enough water, you produce less urine and it is more concentrated (often yellow in appearance). If you have drunk too much water, you produce more urine and it is less concentrated (clear in appearance).

Your kidneys control how much urea, salts and water are released in your urine. They do this by filtering your blood for these substances and then reabsorbing the correct amount of each that you need. Your urine leaves your kidneys and is stored in your bladder until you urinate.

TIP
To help you revise, draw a flow diagram to show how water balance is maintained.

Water balance

You lose water from your body when you urinate, sweat and breathe out (as water vapour). You have no control over this water loss. Ions and urea are also lost with this water in your urine and sweat. Urea is the result of excess protein that your body has broken down to excrete. Your body is able to control how much water is lost by controlling the amount of water in your urine and its volume. If you do not have enough water, you produce less urine and it is more concentrated (often yellow in appearance). If you have drunk too much water, you produce more urine and it is less concentrated (clear in appearance).

Your kidneys control how much urea, salts and water are released in your urine. They do this by filtering your blood for these substances and then reabsorbing the correct amount of each that you need. Your urine leaves your kidneys and is stored in your bladder until you urinate.
The concentration of your blood is monitored by a part of your brain called the osmoregulatory centre. This is next to your pituitary gland. This gland releases a hormone called anti-diuretic hormone (ADH) into your bloodstream. This is carried to its target organs, your kidneys, in your blood. The volume of ADH that is excreted by your pituitary gland controls the volume of urine you excrete.

When you consume more water than you need, less ADH is produced. This means your kidneys release more water into your urine. You will urinate more dilute urine. When you consume less water than you need, more ADH is produced. This means your kidneys release less water into your urine. You will excrete less, but more concentrated, urine.

This is an example of negative feedback control. Here your body has detected a change (high or low water concentration in your blood) and made an adjustment to return it back to normal. All examples of homeostasis involve negative feedback.

**Protein removal**

If you consume too much protein in your diet, it is broken down by your digestive system into amino acids, which are absorbed into your blood. These are then broken down further into ammonia in your liver. This is a toxic substance and so is immediately converted into urea to be excreted. This is filtered from your blood in your kidneys and excreted in your urine.
The kidney

Your two kidneys are bean-shaped and found in your lower back, either side of your spine. Blood is brought to them in the renal arteries. It is filtered by the kidneys before being taken away by the renal veins. The ureter forms a third tube that leads from each kidney and takes urine to the bladder. Each kidney has an outer area called the cortex and an inner area called the medulla. There are about a million smaller structures called nephrons that are found in both the cortex and the medulla. It is these nephrons that remove excess water, ions and urea.

This process can be summarised in three steps:
1. filtration of glucose, urea, salts and water
2. selective reabsorption of all glucose, some salts and some water
3. excretion of all urea, excess salts and water.

This leaves the correct concentration of water and salts in your blood. It removes all the toxic urea and any excess water and salts.

Kidney failure

Kidney failure happens when a person’s kidneys are no longer able to filter their blood properly. There are many reasons why this might occur. Injury, communicable diseases and inherited conditions can all cause this. Kidney dialysis or a transplant operation are the two possible treatments for kidney failure.

Kidney dialysis

When a patient is undergoing kidney dialysis their blood is temporarily removed from their body and is filtered in a machine. The machine becomes an artificial kidney. This process takes several hours and must happen several times per week. It is only used when a person would die from the high levels of urea in their body. It does not cure the kidney failure but temporarily allows the patient to survive until a transplant can occur.

In the dialysis machine the patient’s blood passes alongside a liquid called dialysis fluid. The two liquids are separated by a selectively...
permeable membrane and have the same concentration of glucose and salts. This means there is no net diffusion of either substance. The dialysis fluid has no urea, however. So this diffuses from a high concentration in the patient’s blood to a lower one in the fluid. The patient’s ‘clean’ blood is then returned to them.

**Kidney transplant**

If both of a patient’s kidneys are not working properly then a transplant is a more permanent solution than dialysis. You have two kidneys but many people can survive with only one. For this reason kidneys for transplants can come from living people as well as those that have donated their organs after death.

Only kidneys from appropriate donors can be transplanted. A donor is appropriate if the patient’s immune system will not recognise antigens and attack the kidney as foreign after it has been transplanted. This is called rejection if it occurs. Drugs are given to the patient after the operation to reduce the chances of rejection by supressing their immune system. Because the donor’s and patient’s organs must match, many of the kidneys donated come from close family members, and only then if a close match is found by tissue typing. Here there is a much reduced chance of rejection. The operation takes several hours but is a permanent cure for kidney failure.

**Test yourself**

9 Give the two treatments for kidney failure.
10 How is water lost from your body?
11 Describe how ADH regulates your water content.
12 Describe why water regulation is an example of negative feedback.

---

**Hormones in human reproduction**

The sex hormones in women are **oestrogen** and **progesterone**. **Testosterone** is the male sex hormone. These hormones are involved in the development of secondary sex characteristics in puberty. These are shown in Table 12.3.

Table 12.3 The secondary sex characteristics caused by sex hormones during puberty.

<table>
<thead>
<tr>
<th>Female secondary sex characteristics</th>
<th>Male secondary sex characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth of breasts</td>
<td>Increased growth of testes and penis</td>
</tr>
<tr>
<td>Hips widen for childbirth</td>
<td>Increased muscle mass and broadening of shoulders</td>
</tr>
<tr>
<td>Growth of facial and underarm hair</td>
<td>Deepening of voice</td>
</tr>
<tr>
<td>Growth of pubic hair</td>
<td>Growth of facial and underarm hair</td>
</tr>
<tr>
<td>Growth spurt</td>
<td>Growth of pubic hair</td>
</tr>
<tr>
<td></td>
<td>Growth spurt</td>
</tr>
</tbody>
</table>

Testosterone in males is secreted by the testes. Oestrogen and progesterone in females are produced by the ovaries. The testes and ovaries are therefore glands. As well as causing the secondary sex
characteristics shown in Table 12.3, testosterone stimulates the production of sperm. Oestrogen and progesterone are two key hormones in the menstrual cycle. Interestingly, the sex hormones oestrogen and progesterone are also found in many other vertebrates.

The menstrual cycle

After puberty, women undergo a reproductive cycle of around 28 days until they reach the menopause. At this point a woman’s menstrual cycle stops and she is no longer able to have children. This occurs between approximately 45 and 55 years of age. There is no menopause for men and they are often able to produce sperm for much longer than women menstruate (have periods). But older men produce less testosterone than younger ones and their sperm become less able to fertilise an ovum (less fertile).

Oestrogen is responsible for the thickening of the lining of a woman’s uterus. This happens in the first few days after menstruation. The lining thickens in preparation for the settlement of a fertilised ovum, which travels down a fallopian tube to the uterus. The release of a mature ovum from an ovary into the fallopian tube happens on about day 14 of the menstrual cycle. This is called ovulation. It takes several days to travel down a fallopian tube and be fertilised by a sperm cell. If a fertilised ovum does embed in the lining of the uterus, the hormone progesterone continues to be produced to prevent menstruation. This would abort a developing fetus. If an ovum does not settle, less progesterone is produced and a woman menstruates. This lasts several days and can be painful, causing cramps. Its beginning marks the start of the next 28-day menstrual cycle. The hormonal control of the menstrual cycle is very delicate. It is often altered by stress or exercise.

There are four main hormones involved in the menstrual cycle. They are shown in Table 12.4, together with the effects they have. Figure 12.14 shows these effects in a flow diagram.

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Released by</th>
<th>Target organ and effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Follicle-stimulating hormone (FSH)</td>
<td>Pituitary gland</td>
<td>• Causes an ovum to mature in the ovary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Stimulates ovaries to produce oestrogen</td>
</tr>
<tr>
<td>Oestrogen</td>
<td>Ovaries</td>
<td>• Causes lining to thicken in first half of the cycle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pituitary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High oestrogen concentration switches off release of FSH and switches on release of LH</td>
</tr>
<tr>
<td>Luteinising hormone (LH)</td>
<td>Pituitary gland</td>
<td>• Ovary</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Stimulates ovulation (release of the ovum from the ovary)</td>
</tr>
<tr>
<td>Progesterone (produced if fertilised ovum implants in uterus)</td>
<td>Ovaries (corpus luteum)</td>
<td>• Uterus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Maintains thick uterus lining if fertilised ovum implants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High concentrations of progesterone in pregnancy stop the cycle</td>
</tr>
</tbody>
</table>
Follicle-stimulating hormone (FSH) is released by the pituitary gland. This causes an ovum to mature in an ovary. This happens inside a follicle. It also causes the ovaries to produce and release oestrogen. This causes the lining of the uterus to thicken in the beginning of the menstrual cycle. The pituitary gland detects this high level of oestrogen and stops producing FSH. Instead the pituitary gland starts to secrete luteinising hormone (LH). This stimulates ovulation, releasing an ovum from an ovary. After ovulation the follicle from which the ovum was released develops into the corpus luteum. This releases progesterone, which inhibits the release of both FSH and LH and in doing so maintains the lining of the uterus in the second half of the cycle. If a fertilised ovum settles and implants, the levels of progesterone are maintained, resulting in no menstruation. If an ovum does not implant, the levels of progesterone reduce. This triggers menstruation.

KEY TERMS

Follicle-stimulating hormone (FSH) A hormone produced by the pituitary gland that causes an ovum to mature in an ovary and the production of oestrogen.

Follicle A structure in an ovary in which an ovum matures.

Luteinising hormone (LH) A hormone produced by the pituitary gland that stimulates ovulation.

Corpus luteum After ovulation the empty follicle turns into this and releases progesterone.

Test yourself

13 Name the two key hormones in the menstrual cycle.
14 Where is oestrogen produced?
15 Describe secondary sexual characteristics in women.
16 Describe why the menstrual cycle is an example of negative feedback.

Contraception

Contraception is the name for the methods or devices that stop women becoming pregnant. It is often called birth control or family planning. Some forms of contraception are permanent, while others are only temporary. Contraception is an ethical issue. This means that some people disagree with it for religious or moral reasons. Some religions, including perhaps most famously the Roman Catholic Church,
of which there are more than a billion members worldwide, only officially accept ‘natural family planning’. This is when the male doesn’t ejaculate inside the female’s vagina during sex, particularly when an ovum is likely to be fertilised (around days 13–17). This is different from abstinence, which is stopping having sex altogether. Other religions such as Judaism, Hinduism and Buddhism have wider ranging views that allow both ‘natural’ and artificial contraception.

One method of contraception for men is to have a vasectomy. Here a short and relatively simple operation stops sperm travelling along the sperm ducts that link the testes to the penis. These can be tied, and later be untied if the male would like to have children again. The sperm ducts can also be cut. This is a permanent form of contraception for men. A similar procedure can occur in women. Here the fallopian tubes are tied or cut, which stops ova reaching the uterus. This is called tubal ligation and again can be reversed if the tubes are tied but not if severed.

Other forms of contraception are barriers that stop ova and sperm meeting. Condoms are a very widespread form of contraception. They surround an erect penis and stop sperm entering the vagina. They have been used for over 400 years. There are larger female condoms, often called femidoms, which sit inside the vagina and stop sperm in the same way. These are less common. Another contraceptive that forms a barrier is the diaphragm. This is a small plastic dome that is inserted into the vagina to cover the cervix. This is the narrow join between the vagina and the uterus. Contraceptive sponges work in the same position. They are also covered in a chemical called a spermicide, which kills sperm cells. Intrauterine devices are plastic or metal devices that are placed inside the uterus by a doctor or a nurse and prevent an embryo implanting. Some also now contain progesterone, which also stops implantation.

Condoms protect against the spread of many sexually transmitted diseases (STDs) because they stop the contact of all bodily fluids. Other forms of contraception are less effective at stopping STDs. The diaphragm and the sponge don’t stop their transmission, for example.

The use of contraceptive hormones

Other forms of contraception involve the use of hormones to stop fertilisation of ova. The oral contraceptive pill (often known simply as the pill) contains both oestrogen and progesterone. It is a very common form of contraception with over 100 million women worldwide using it.

The woman takes a pill each day at the same time. This can either be for the entire cycle or just the first 21 days followed by a week with no pills. The last seven pills in a 28-day packet are placebo pills. They don’t have the hormones in. During this week a woman menstruates and so is highly unlikely to become pregnant. During the 21 days when the pill contains hormones, a delay of over 12 hours in any one day reduces the effectiveness of the contraception. The pill often helps women keep their periods more regular, particularly when they are younger.

The pill prevents ovulation by inhibiting the production of FSH. It can also thicken the mucus in the neck of the uterus so it is harder for sperm
Hormonal coordination in humans

to reach the uterus. It can also thin the lining of the uterus so there is a reduced chance of a fertilised ovum settling to develop into a fetus.

The pill is more effective than many other contraceptive methods. If the pill is taken correctly for the first year the chance of becoming pregnant is less than 1%. A huge positive side effect of taking the pill is the obvious reduction in unwanted pregnancies and complications that can arise from childbirth in these cases. Other advantages include lighter periods (less menstruated blood each month), a reduced risk of cancer of the ovaries and the uterus and the possible reduction of premenstrual symptoms (PMS). Negative side effects include headaches, feeling sick (nausea), breast tenderness and mood swings. The pill does not stop the transmission of STDs.

The same hormones oestrogen and progesterone can also be delivered into a woman’s blood in a small device implanted under her skin or a patch temporarily stuck to it. They are as effective at reducing pregnancy as the oral pill. Patches last 7 days and are applied for the first 3 weeks of the menstrual cycle. They are not applied during the last week and menstruation usually occurs at this time. The implant is about 4 cm long and is usually placed beneath the skin of a woman’s upper arm. It can function for up to 3 years. Many women using the implant have lighter periods, and some have no periods at all. They both have many of the advantages of the oral pill.

Test yourself

17 Define the term ‘vasectomy’.
18 Describe why contraception is an ethical issue.
19 Describe how the contraceptive pill is taken.

The use of hormones to treat fertility

You learnt in the previous section that the sex hormones oestrogen and progesterone are used in the contraceptive pill, patch or implant. Other related hormones can actually be used to have the opposite effect. That is, they can be used to treat infertility or help a woman become pregnant.

Some women have naturally low levels of the two hormones FSH and LH. (Look back at Table 12.4 to remind yourself about these hormones.) These both work with oestrogen and progesterone to control the menstrual cycle. Some infertile women cannot produce sufficient FSH to begin maturing an ovum in an ovary. Simple injections of FSH and LH can increase the levels in the woman’s blood. This may allow her to become pregnant naturally.

If this does not work some woman undergo in vitro fertilisation (IVF). In vitro is Latin for ‘in glass’, which means outside of the body. ‘Inside the body’ is in vivo. Babies born following IVF treatment are often called ‘test-tube babies’, even though test
Gestation is the time between fertilisation and birth. The first step in IVF involves injections of FSH and LH. These hormones stimulate the maturation of several ova. A small operation removes these ova from the woman’s ovaries and they are introduced to a man’s sperm. The sperm cells sometimes fuse with the ova naturally to fertilise them. Sometimes the nucleus of a sperm cell is injected into an ovum. The fertilised ovum then develops into embryos (small balls of cells). A second small operation places one or more embryos back into the lining of the uterus. Nine months later gestation is over and the woman has her ‘test tube’ baby or babies.

What happens to the unused fertilised embryos is an ethical decision. This means that some people disagree with it for religious or moral reasons.

These fertility treatments allow women, who otherwise might not be able to, to have a baby of their own. There is often a very natural strong urge to do this. The treatments themselves can be emotionally and physically stressful. Unfortunately the success rates are not high. This has led doctors to implant more fertilised ova during IVF and has led to mothers having larger numbers of children than they might have wanted.

### Negative feedback

The homeostatic regulation of blood glucose levels by the hormones insulin and glucagon is an example of negative feedback control. The production of ADH to control the homeostatic regulation of the water in your urine is another example. The secretion of hormones in the menstrual cycle is another.

![Figure 12.20](image) This basic sequence applies to all hormonal control.

[TIP]
Learn all examples of negative feedback control. What similarities and differences do they have? Draw a flow diagram for all four to help you remember.
The formation of thyroxine in the thyroid gland is another example of negative feedback control. The thyroid gland is one of your largest glands. It is found in your neck. It produces hormones that control how quickly your body uses energy, how quickly it makes proteins, and how sensitive it is to other hormones. This and related hormones act on almost every one of your cells and control your metabolic rate. It therefore plays an important role in growth. Your pituitary gland produces thyroid-stimulating hormone (TSH). This stimulates the release of thyroxine from your thyroid gland. If you do not have enough iodine in your diet you are less able to produce thyroxine. Then your pituitary gland will produce more TSH to try to increase the production of thyroxine. This can enlarge your thyroid gland and form a goitre in your neck.

Adrenaline is a hormone that is secreted by your adrenal glands, which sit just above your kidneys. Unlike the previous examples, the formation of adrenaline is not an example of negative feedback control. Adrenaline is most commonly associated with the ‘fight or flight’ response. This occurs in situations that your brain perceives could threaten you or those around you. Under these circumstances your brain produces a series of hormones ending in adrenaline. This happens very quickly to avoid any damage from the threat. It causes your heart rate to increase, providing your muscles with more glucose and oxygen needed for respiration. This releases the energy you may need to fight or run away. It also increases your blood glucose level, blood pressure and suppresses your immune system. All of these are designed to give you a short-term energy boost.

**KEY TERMS**

**Thyroid-stimulating hormone (TSH)** A hormone produced by your pituitary gland that regulates your thyroid gland.

**Thyroid gland** A gland in your neck that produces thyroxine to regulate how quickly your body uses energy and makes proteins, and how sensitive it is to other hormones.

**Goitre** A medical condition in which your thyroid gland in your neck swells.

**Adrenaline** A hormone produced by your adrenal glands that causes an increase in heart rate ready for a ‘fight or flight’ response.

**Adrenal glands** Glands that produce adrenaline.

**Figure 12.21** When in a dangerous situation, adrenaline causes your heart rate to increase to supply your muscles with more energy so that you can run or stop and fight.

**Test yourself**

- 24 What does thyroxine control?
- 25 Where is thyroxine produced?
- 26 Describe the symptoms of over-production of TSH.
- 27 Describe why thyroxine is an example of negative feedback.
Chapter review questions

1. What type of organs produce hormones?
2. Describe how hormones move around your body.
3. Describe how water is lost from your body.
4. Describe what your urine would be like if you were dehydrated.
5. Lick the back of your hand and blow on it. Describe what this is a model for and explain why it feels cold.
6. Name the glands that produce testosterone in men.
7. Define the term ‘contraception’.
8. Suggest an advantage of using a condom over a diaphragm or sponge.
9. Give the general name for an organ that a hormone acts upon.
10. Describe what happens when insulin is released into your blood.
11. Explain the reason for type 1 diabetes.
12. Describe how people with type 2 diabetes treat the condition.
14. Give the function of oestrogen in the menstrual cycle.
15. Describe what happens when progesterone levels drop towards the end of the menstrual cycle and why this might occur.
17. Describe how the diaphragm and sponge stop pregnancy.
18. Name the two hormones in the contraceptive pill.
19. Explain how the contraceptive patch or implant works.
20. Explain how hormones can be used to treat infertility.
21. Describe the function of thyroid-stimulating hormone.
22. Explain why you need to be able to store glucose.
23. Explain why the regulation of blood sugar is an example of negative feedback control.
24. What does ADH stand for?
25. Name the gland that releases ADH.
26. Explain how the levels of ADH are altered if you drink more or drink less.
27. Describe the three key processes that occur in a nephron.
28. Describe the process of kidney dialysis.
29. Describe how FSH and LH regulate the menstrual cycle.
30. Name the structure in which an ovum matures.
31. Describe the role that the corpus luteum has during early pregnancy.
32. Describe the process of in vitro fertilisation (IVF).
33. Explain why some people have multiple births following IVF treatment.
1 The human endocrine system consists of structures that can secrete hormones.
   a) i) Describe what a hormone is. [1 mark]
   ii) Which of the following structures secrete hormones? [1 mark]
       A Ventricles  C Glands
       B Arterioles  D Ducts
   iii) Describe how the hormones that regulate the menstrual cycle travel around the body. [1 mark]

2 Figure 12.22 shows the concentrations of blood glucose in the body of a student after they ate a chocolate bar.

   ▲ Figure 12.22
   a) What is the highest concentration of blood glucose recorded? [1 mark]
   b) i) Sketch a graph to show what you would expect the blood glucose concentration to look like if the student had diabetes. [3 marks]
   ii) Which hormone can a person with type 1 diabetes not produce? [1 mark]
       A Adrenalin  C Glucagon
       B Insulin    D Thyroxin
   iii) Name the hormone a person with type 1 diabetes cannot produce. [1 mark]
   iv) Other than injecting themselves with hormones, what else can a person with diabetes do to manage their condition? [1 mark]
   c) i) Why is glucose needed by the body? [1 mark]
   ii) Name the organ that monitors blood glucose concentrations. [1 mark]
   d) Sometimes blood glucose concentrations drop too low. Describe as fully as you can how blood glucose concentrations can be brought back to normal. [4 marks]

3 The body uses osmoregulation to control the amount of water it contains.
   Table 12.5 shows the main inputs and outputs for water in the body.

<table>
<thead>
<tr>
<th>Inputs of water</th>
<th>Volume in cm³</th>
<th>Outputs of water</th>
<th>Volume in cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drink</td>
<td>1400</td>
<td>Sweat</td>
<td>750</td>
</tr>
<tr>
<td>Food</td>
<td>X</td>
<td>Urine</td>
<td>1350</td>
</tr>
<tr>
<td>Metabolic water</td>
<td>300</td>
<td>Faeces</td>
<td>100</td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td></td>
<td>300</td>
</tr>
<tr>
<td>Total</td>
<td>2500</td>
<td>Total</td>
<td>2500</td>
</tr>
</tbody>
</table>

   ▲ Table 12.5
   a) i) Using the information in the table calculate the volume of water gained from food (X). [1 mark]
   ii) What is the process Y, which has an output volume of 300 cm³? [1 mark]
   b) i) Which organ is responsible for producing urine? [1 mark]
   ii) If a person does not drink enough on a hot day the volume of urine produced will be less. Explain how the body reduces the volume of urine produced. [3 marks]

4 Hormones play an important role in regulating the menstrual cycle. Figure 12.23 shows the change in thickness of the lining of the uterus during the menstrual cycle.

   ▲ Figure 12.23
   a) i) Use Figure 12.23 to explain what happens to the thickness of the uterine lining over the course of the menstrual cycle. [3 marks]
   ii) Suggest which day the ovum is released. [1 mark]
   b) Explain how the hormones FSH, oestrogen and LH control the menstrual cycle. [4 marks]

5 a) The oral pill, the patch and the implant prevent pregnancy by releasing hormones that stop ovulation. Which organ do these hormones act on? [1 mark]
   b) Suggest two drawbacks with the use of all types of female contraception. [2 marks]

6 The first stage in *in vitro* fertilisation (IVF) is the fertilisation of an ovum by a sperm.
   a) Describe what occurs after the ovum has been fertilised. [2 marks]
   b) Often in IVF multiple ova are fertilised.
      i) Suggest an advantage of this. [1 mark]
      ii) Suggest a disadvantage of using multiple embryos. [1 mark]
Ethical choices in science

Any new development in science leads to decisions about its use. Since the birth of Louise Brown in 1978, the first ‘test-tube baby’ born through IVF, there have been ongoing debates about the use of IVF and funding of this procedure on the NHS.

The reasons for the continued interest in this topic are both the ongoing scientific advances in the field and the fact that use of IVF has moral and ethical implications. Morals involve an individual’s principles and their judgement of what is right or wrong. Ethics are principles that a group of people or a society agrees are right or wrong.

The Government and hospitals use ethics committees to make ethical decisions. These involve a group of people from different backgrounds who discuss the issues. Usually ethical decisions are based on what leads to the best outcome for the greatest number of people.

In 2013 the guidelines for IVF in the UK were updated to give three full cycles of IVF to women under 40 years old who have not conceived after 2 years of trying. The success rate of IVF depends on a number of factors, including the age of the woman undergoing treatment. Younger women are more likely to have healthier ova, which increases the chances of success.

Not everyone can be given IVF and there is a waiting list for the procedure. Fertility clinics need to make decisions about whether a treatment is suitable and ethical.
Questions

1 Imagine you are a member of the ethics committee of a fertility clinic. Read the four case studies below and decide who should be given the three cycles of IVF treatment. You need to justify your reasons.

Couple W are in their late twenties and have been married for eight years. They have been trying for a child since they were married with no success. They would like IVF treatment.

Couple X are in their mid-thirties and have three daughters already, but they really want a son. They would like to use IVF treatment and pre-select a male embryo to implant.

Couple Y are in their early thirties. One of the couple has an inherited condition called Charcot–Marie–Tooth disease, which causes weakness and wasting of the muscles below the knees and loss of sensation in the fingers. The couple would like IVF treatment in order to pre-select a healthy embryo.

Couple Z have been married for 3 years and they are in their mid-forties. Both have children from their previous relationship. They have been trying for a child of their own for 2 years and would like IVF to assist them in getting pregnant.

2 Give two reasons why some groups of people might be against all IVF treatment.

3 Decisions are not just made about ethics; personal, social, economic and environmental implications need to also be considered. Give an economic reason why some people are against IVF treatment.

4 In February 2015 the UK Parliament voted to approve the use of three-person IVF. Research what this is and the ethical arguments people have for and against its use.

▲ Figure 12.26
Some people think that plants can’t move. Are they correct? Well a plant cannot move its entire self to a different location. Some plants, such as tumbleweeds often seen blowing across roads in Wild West American films, can be moved by other things like the wind, but they cannot move all by themselves. Plants are able to move parts of themselves though. Roots grow downwards seeking water, while shoots spiral upwards looking for and growing directly towards light. The Venus fly trap closes its traps to catch insects. The *Mimosa* plant folds its leaves to stop it being eaten. Much of your growth is controlled by hormones, and these are essential for growth in plants too.
All plants want to grow towards the light. Most do this quite slowly so it doesn't seem as if it is much of a race to us, but plants do race upwards towards the light. More light means more photosynthesis, which means more glucose produced. This in turn means more growth and reproduction. Plant growth of stems towards light is called **positive phototropism**. Shortly before his death, Charles Darwin (1809–1882), a scientist better known for his theory of evolution by natural selection, and his son were involved in the initial discovery that grass seedlings grow towards the light.

Plants also need to grow towards water, which is usually downwards, for photosynthesis. Their roots therefore must grow in the opposite direction into the ground. This is called **positive gravitropism** (or geotropism). They are responding to gravity and growing into the ground.

**Auxins**

**Auxins** are a group of plant hormones that affect plant growth. They are involved in phototropism and gravitropism. The presence of higher concentrations of auxins makes individual cells grow fast and become longer. We call this **cell elongation**. If the cells on one side of a plant shoot have more auxins they will elongate more. This will cause the stem to curve. In order to make a stem curve towards the light the auxins concentrate on the other side of the stem. These are the cells that need to grow longer to bend the stem towards the light. We say that the auxins concentrate on the dark side of the stem.

Gravitropism works in the same way. Here roots need to grow downwards towards water. If a root is growing horizontally, the cells on the top side will need to grow longer to curve the tip downwards.

Auxins are mainly produced in the tips of shoots and roots but do diffuse through the plant to other parts where needed.

Plant roots are also able to sense and grow towards water. This response is called **hydrotropism** and usually overpowers gravitropism. If you were to grow cress seeds in a Petri dish with droplets of water that have condensed on the surface of the lid, the roots may grow upwards towards the water and not downwards as a result of gravity.
Experiments involving auxins

Figure 13.2 shows the results from a number of famous experiments involving auxins. In the first diagram you can see the shoot bending towards the light. The second experiment shows a shoot that has had its top cut off. This has not bent towards the light, which shows that the auxins are produced in the tip. The third experiment shows a shoot with a cover on the tip. This has not bent towards the light, which shows that the light-sensitive cells are in the tip. The fourth experiment shows a shoot that has had an impermeable mica barrier inserted to stop hormones diffusing between cells. The shoot with the insert on the dark side did not bend whilst the one with the insert on the light side did. This shows that hormones diffuse down the dark side of the shoot. The fifth experiment shows a similar experiment to the fourth except the barrier was permeable gelatine not mica. The shoot did bend towards the light, showing that auxins can diffuse through gelatine.

Other hormones

Plants have other hormones called gibberellins, which are involved in plant growth. Some help with stem elongation while others are involved in the dormant period before a seed germinates, and the germination process itself. Others help form flowers and fruits.

Ethene is a third plant hormone. Its main role is the ripening of fruit, but it does control cell division and help flowers open and is involved in the dropping of leaves. It is present in high concentrations in rotting fruit. If fresh fruit is kept near rotting fruit, the ethene will diffuse and cause the other fruit to rapidly rot, producing more ethene. Perhaps this is the cause of the saying “one bad apple spoils the bunch”.

Investigate the effect of light or gravity on the growth of germinated seedlings

In this practical you will examine the effect of light on the growth of germinated seedlings.

Method

1. You will be provided with a small number of newly germinated radish seedlings (or those of another small, fast-growing plant).
2. Measure the length of the seedlings from the seed to the tip of the stalk and record this starting measurement.
3. Over one seedling, place a yoghurt pot painted black (or other container that can exclude light).
4. Over a second seedling, place a yoghurt pot painted black with a hole cut into the top so that light can only come in from the top. Place this under a light bank or bench light, or on a windowsill.
5. Over a third seedling, place a yoghurt pot painted black with a hole cut into the side so that light can only come in from the side. Place this under a bench light or on a windowsill so that the light is shining in from the side.
6. After 3–4 days, remove the yoghurt pots and record what has happened to the length and growth direction of the seedlings. If the seedlings are difficult to measure, use string to help you work out their total length.

Questions

1. Calculate the amount of growth that occurred in each seedling over the course of the experiment.
2. In which direction have the shoots grown in each pot? Draw a sketch and describe your observations.
3. Explain why the growth was different in each pot.
4. Why is it important that plant shoots can respond to light?

KEY TERMS

Impermeable Through which a substance cannot pass.
Gibberellins Plant hormones responsible for cell elongation, seed dormancy and germination.
Ethene A plant hormone that ripens fruit.
Auxin and plant growth

Barley seedlings were grown, being lit from directly above for 5 days, so that the seedlings produced showed straight vertical growth. A toothpick was placed next to the plant to show the direction of starting growth.

Auxin (IAA) of different concentrations was mixed with lanolin paste (a natural grease) and applied to the left-hand side of a seedling between 5 mm and 10 mm from the tip of the shoot.

The seedlings were then placed in the dark for a further 5 days. When they were removed the angle of growth away from the toothpick could be measured. The results of the experiment are shown in Table 13.1.

Questions
1. Plot the results as a line graph.
2. Use your graph to predict the angle of growth if 6 mg/dm$^3$ of IAA was used.
3. Why was it important that the seedlings were kept in the dark following the treatment with lanolin?
4. Explain why the growth angle increased as the concentration of IAA increased.

<table>
<thead>
<tr>
<th>Concentration of IAA in mg/dm$^3$</th>
<th>Angle of growth in degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>12</td>
<td>19</td>
</tr>
</tbody>
</table>

Test yourself
1. Name a plant hormone other than auxin.
2. Name the process by which plant roots grow downwards.
3. Describe an experiment in which you prove that auxins are made in the tip of shoots.
4. Describe why ripe bananas are often not kept with other fruit.

Show you can...

Explain how plants grow towards the light. Draw a diagram as part of your answer.

Use of plant hormones

Agriculture is the growth of animals and crops for food, fuels or medicines. Horticulture is the growth of plants. It may include crops or vegetables but also includes plants that are grown for the way they look or smell. Plant hormones are widely used in both agriculture and horticulture.
Selective weedkillers

Auxins are used in many selective weedkillers. These will kill broadleaved plants such as dandelions and daisies but not the narrower leaved grass plants. This is because broadleaved plants have a greater surface area of leaf to absorb the weedkiller. This means we can spray it on lawns and it will only kill undesirable weeds. These hormones cause some plants cells to grow uncontrollably and others to stop growing. This kills the plant.

Rooting powder

Taking plant cuttings is a way of propagating (or increasing the number of) plants that a gardener has. This is shown in Figure 13.6. The cut end of the stem is then dipped in a rooting powder and placed into the soil. Rooting powder contains auxins, which help the cutting form roots. Taking cuttings is an artificial asexual form of plant reproduction. The offspring have the same genetic information (DNA) as their one parent. They are clones.

Tissue culture

Auxins are also used in tissue culture. This is another example of artificial asexual reproduction in which small numbers of cells are removed from the parent plant. These are placed into a growth medium and grow into cloned copies.

Fruit ripening

We have seen that ethene is produced by plants to ripen their fruits. Because it takes so long to transport fruits by ship from the tropics to markets in Europe, they are often picked before they are fully ripe. This stops them rotting on their long boat journey. (It might prove too expensive to transport them by air.) They are sprayed with ethene a short time before arriving so that the fruit is beginning to ripen as it placed on the shelves.

Gibberellins

You learnt above that gibberellins are used by plants for stem elongation, seed dormancy and germination. They are often used in agriculture and horticulture for beginning germination as well as helping plants flower and to increase the size of their fruit.

Test yourself

5 Name three plant hormones.
6 Define the term ‘propagation’.
7 Describe how rooting powder is used.

Show you can...

Explain how plant hormones are used.
Chapter review questions

1. Define the term ‘positive phototropism’.
2. Define the term ‘positive gravitropism’.
3. Describe the effect that auxins have upon cells.
4. Name the process by which auxins move in a plant.
5. Name the process by which roots grow towards water.
6. Give the three main uses of plant hormones.
7. Describe an experiment in which you investigate the effect of light on newly germinated shoots.
8. Explain in detail why plant roots usually grow downwards.
9. Describe the role of auxins in phototropism.
10. Define the term ‘cell elongation’.
11. Describe what would happen to a shoot if you cut its tip off. Explain why.
12. Describe what would happen to a shoot if you cut its tip off, placed a layer of impermeable mica on it and then put the tip back on. Explain why.
13. Describe what would happen to a shoot if you cut its tip off, placed a layer of permeable gelatine on it and then put the tip back on. Explain why.
14. Describe the effects of the plant hormone ethene.
15. Describe the effects of the gibberellin plant hormones.
16. Explain how hormones are used in selective weedkillers.
17. Explain how hormones are used in rooting powder.
18. Explain how hormones are used in fruit ripening.
19. Describe an experiment in which you investigate the effects of auxins on the growth of shoots.
20. Which famous scientist and his son first discovered phototropism?
21. Explain why auxins diffuse from the tip of a plant’s shoot.
22. Describe what would happen to a shoot if you cut halfway through it on its dark side and placed a layer of impermeable mica in the gap. Explain why.
23. Describe what would happen to a shoot if you cut halfway through it on its light side and placed a layer of impermeable mica in the gap. Explain why.
24. Suggest at what point fruit would produce the most ethene.
25. Explain the difference between agriculture and horticulture.
Practice questions

1 Joe wanted to propagate a geranium plant.

He did this by taking cuttings and using rooting powder to make new roots grow. He decided to compare two different brands of rooting powder, Rapid-Root and Ready Root, along with water, to see which was more effective. The results are shown in Table 13.2 below.

<table>
<thead>
<tr>
<th>Cutting</th>
<th>Water</th>
<th>Ready Root</th>
<th>Rapid-Root</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Mean</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

a) i) Calculate the mean number of roots produced when Joe used Rapid-Root. [1 mark]

ii) What conclusion could Joe draw from the data? [2 marks]

b) Rapid-Root claims to produce 75% more roots than other rooting powders. Calculate whether this claim is true. [3 marks]

c) i) Name the plant hormone found in rooting powder. [1 mark]

ii) Suggest another plant hormone that can be used in agriculture and explain its use. [2 marks]

d) Make a prediction about the appearance of the plants that will grow from the cuttings. [1 mark]

2 Charles Darwin and his son Francis famously discovered that growing seedlings respond to light. Two students repeated their experiment by observing the growth of five grass seedlings by doing the following:

- Seedling A: normal
- Seedling B: tip covered in tin foil
- Seedling C: stem covered in tinfoil
- Seedling D: tip covered in clingfilm
- Seedling E: tip cut off

The seedlings were lit from one side by a lamp, and were left to grow for a week.

a) Sketch a diagram to show what each plant would look like after a week. [3 marks]

b) The differences in growth of the seedlings was caused by a hormone, this hormone diffuses into the plant tissue. In which of the following ways would it diffuse? [1 mark]

A Shaded side of the seedling  C Top of the seedling
B Lit side of the seedling  D Bottom of the seedling

The seedlings were lit from one side by a lamp, and were left to grow for a week.

2 A student had the following equipment:
- 16 fast-growing radish seedlings
- 4 Petri dishes
- cotton wool
- water
- measuring cylinder
- 4 lamps of the same light intensity
- 3 boxes: one with a hole in the side, one with a hole in the top, and one without a hole.

Explain how they could use this equipment to measure the effect of light on the growth of germinating seedlings. [6 marks]
Ethene is a hormone that is commercially used to ripen fruit before it goes on sale. It is important that farmers and suppliers therefore know how ripe the fruit is and how long it will take to fully ripen. One way this can be done cheaply and easily is using the starch scale. During fruit ripening large starch molecules are broken down in the flesh of fruits into smaller sugar units, making the fruit taste sweeter. Carrying out a simple starch test can monitor this process. Wearing eye protection, a sample fruit from a batch is cut in half and placed in a dish of potassium iodide (iodine solution). The fruit is left to absorb the iodine solution for 1 minute and then any excess is washed away and the fruit patted dry. The fruit is then compared to a 10-scale chart (see Figure 13.8) and a level of ripeness given.

Questions

1. Use your previous understanding of the starch test to explain why number 1 is the least ripe fruit and number 10 is over-ripe.

2. Figure 13.9 shows the results of six sample apples, A–F, that have all been treated with an iodine solution. Use Figure 13.8 to help you decide a level of ripeness (1–10) for each of them. Do not ask anyone else’s opinion for this. Record your result in a table like the one below.

<table>
<thead>
<tr>
<th>Apple</th>
<th>Level of ripeness (1–10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Your name</td>
</tr>
<tr>
<td>A</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
</tr>
</tbody>
</table>

3. Share your results with four other students and complete your table of results. Work out a mean level of ripeness for each apple and record it (this must be a whole number).

4. Data are considered reproducible if when another person repeats the investigation the same results are obtained. How reproducible were your results overall? Which apple gave you the most reproducible results? Which gave the least reproducible results?

5. Why do you think experiments involving comparisons to standards tend to produce less reproducible results?

6. How are reproducible results and repeatable results different?

7. How else do you think the ripeness of fruit could be measured?

**KEY TERM**

Reproducible A measurement is reproducible if the investigation is repeated by another person or by using different equipment or techniques and the same results are obtained.
Imagine cutting off your arm and allowing a genetically identical copy (clone) of you to grow from it. This sounds crazy in humans, but other species including plants, worms, fungi, coral and animals like starfish can reproduce in this way. They don’t cut themselves up but do reproduce if cut. This is an example of asexual reproduction. Most eukaryotic species like us don’t reproduce like this but do so sexually. You were formed from a sperm and an ovum when your parents sexually reproduced.

This chapter covers specification points 4.6.1.1 to 4.6.1.8 and is called Reproduction.

It covers the structure of DNA, genes, chromosomes and the genome. It also covers meiosis, the Human Genome Project, protein synthesis, sexual and asexual reproduction, sex determination and other genetic inheritance.
Reproduction is the biological process by which a parent or parents have offspring. All life on Earth reproduces, and this is one of the seven life processes. Viruses do not reproduce because they are not alive. They are constructed inside their host cell in a process called replication. There are two types of reproduction: asexual and sexual.

### Asexual reproduction

*Asexual reproduction* involves one parent organism having genetically identical offspring. Because of this all offspring are clones of the parent. In asexual reproduction, there is no joining (fusion) of sex cells (gametes) such as sperm and ova in humans, for example. So there is no mixing of genetic information (DNA). The only type of cell division involved here is mitosis. It is important to remember that organisms that are produced asexually may not all look alike. Environmental variation will also affect them.

All prokaryotic bacteria reproduce asexually in a process called *binary fission*. Here the parent bacterium is replaced by two identical daughter bacteria when it divides into two.

Vegetative reproduction occurs in plants and is any asexual reproduction without forming seeds or spores. Spider and strawberry plants form miniature plantlets on runners, for example, which eventually root near the parent plant and begin to grow. Other plants, such as tulips, form bulbs and some, such as dahlias, form tubers.

Plants and algae can also form spores. If these result from meiosis, they have half the chromosome number of their parent and must fuse with another spore in sexual reproduction. Other plants and algae form spores during mitosis. These have the same number of chromosomes...
Sexual and asexual reproduction

Sexual reproduction usually involves two parent organisms, which produce genetically different offspring. The offspring are not clones. Here there is fusion of a gamete from each of the male and female organisms. So the offspring inherit DNA from each parent. In animals, the gametes are sperm and ova. In plants, the gametes are pollen and ova.

Sexual reproduction occurs in eukaryotic organisms. It involves the meiotic production of gametes with half the DNA of the parent. Two gametes then meet and fuse in fertilisation to form a new organism. This is seen in the following classes of vertebrates: birds, mammals, fish and reptiles. It is also seen in many insects. Fertilisation occurs internally in all mammals, but differences occur after that. In most mammals the offspring then develop in their mother’s uterus, nourished by the placenta. However, a few mammals, such as the echidna (Figure 14.2) and platypus from Australia, lay fertilised ova. Other baby mammals develop in their mother’s pouch. These animals include the kangaroo, wallaby and koala.

Formation of gametes uses energy. Some animals produce them in incredibly high numbers. For example, cod fish release four to six million ova at one time. Others, such as humans, produce them in very small numbers. Women only have approximately 30,000 potential ova, and usually only one is released per menstrual cycle. Men release about 50 million sperm per ejaculation. Many birds only produce a small number of offspring at one time. More ova are released by organisms that do not care for their young, such as most fish. These animals therefore need to produce more ova to increase the chances of their offspring growing to sexual maturity.

Sexual reproduction occurs when a male and female organism mate or when gametes from them both fuse independently of the parents. In recent years humans have selected animals to mate together to control the characteristics of the offspring. This is called selective breeding or artificial selection. Dogs, farm animals including cows, and some crops have been bred or grown in this way.

Both sexual and asexual reproduction

Some organisms have evolved to reproduce both sexually and asexually depending upon the conditions. The freshwater flea Daphnia (Figure 14.3) will undergo asexual reproduction early in the year to rapidly increase numbers. Later on when population pressures such as more predators and lack of food increase it switches to sexual reproduction. Malaria parasites reproduce asexually when inside their human host but sexually in the mosquito. Many algae can switch between producing meiotic and mitotic spores to reproduce sexually or asexually.
Twins

Non-identical twins are formed when a woman releases two ova during ovulation. These are then fertilised by two different sperm. Both fertilised ova then embed into the uterus and grow into genetically different organisms. It is possible to have non-identical twins that are different sexes. Identical twins are formed when one fertilised ovum splits into two cells, which then grow into two genetically identical twins. Again it is important to remember that identical twins may not always look alike. Environmental variation caused by factors such as diet, scarring, tattoos and haircuts may make them look different from each other.

Flowering plants all reproduce sexually, although many can reproduce asexually too. In sexual reproduction, they produce pollen as their male gametes and ova as their female gametes. A pollen cell must fuse with an ovum. This forms a zygote, embryo and then seed. For example, in insect-pollinated plants, a bee might transfer pollen from one flower to another on the same plant. This is called self-pollination. Alternatively, if the bee visits a flower on another plant and deposits the pollen, then this is called cross-pollination.

Meiosis

Mitosis is a type of cell division that copies diploid body cells for growth and repair. There is a second type of cell division called meiosis, which makes our sex cells or gametes (sperm and ova). These have half of our DNA so that they can join with another haploid sex cell during fertilisation in sexual reproduction to form a cell with the full amount again. This means that offspring have genetic information (DNA) from two parents.

The four haploid daughter cells produced by meiosis are either sperm or ova in mammals. In fungi they form spores and in plants they form pollen and ova. These gametes all have half the DNA of
Meiosis

● The process of meiosis

Figure 14.6 shows the steps in meiosis. In the first diagram we can see one cell with four chromosomes. The two red chromosomes are from one parent and the blue ones are from the other. There are two pairs of chromosomes, not 23 pairs as in a human cell, to make the diagram a little less confusing.

As in mitosis, the first stage in meiosis is for the nuclear membrane to disappear and for all the chromosomes to shorten and fatten. The chromosomes have already copied themselves completely. If this were a human cell it would have 46 chromosomes and another 46 copies. At this stage the chromosomes have changed from a long thin structure into an X-shape. Each X-shape is a long thin chromosome with its new copy.

As in mitosis, the chromosomes and their copies then migrate to the middle of each cell. This is seen in the third diagram. At this point an amazing process occurs, which does not happen in mitosis. It is called DNA crossover. This occurs when chromosomes touch each other and entire sections swap from one to another. This means that an organism’s gametes are all genetically slightly different.

At this point half the chromosomes and their copies are pulled to one side of the cell and the other half to the other. The cell membrane then starts to pinch inwards and forms two daughter cells. The chromosomes and their copies then line up again in the middle of both the new daughter cells. This is shown in the fourth diagram. The chromosomes split apart from their copies and are pulled to opposite ends of the two cells. The cell membranes then pinch in and form four haploid daughter cells. Crucially these are different from the products of mitosis, because here each cell has half the number of chromosomes of the starting cell and they are genetically different from each other as a result of DNA crossover.
Meiosis only happens for a short time in women while they are growing in their mother’s uterus. This produces several thousand ova in each ovary, which are released once a month when they are menstruating. Women do not complete meiosis at any other point in their lives. Men start meiosis when they reach sexual maturity and continue until they die. The quality and quantity of their sperm may reduce but old men have become fathers. These timescales are relatively similar in other mammals.

The key differences between mitosis and meiosis are shown in Table 14.1.

Table 14.1 The key differences between cell division in mitosis and meiosis.

<table>
<thead>
<tr>
<th></th>
<th>Mitosis</th>
<th>Meiosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cells at beginning</td>
<td>One</td>
<td>One</td>
</tr>
<tr>
<td>Type of cell at beginning</td>
<td>Diploid body cell (23 pairs of chromosomes in humans)</td>
<td>Diploid body cell (23 pairs of chromosomes in humans)</td>
</tr>
<tr>
<td>Number of cells at end (daughter cells)</td>
<td>Two</td>
<td>Four</td>
</tr>
<tr>
<td>Type of cell at end</td>
<td>Diploid body cell (23 pairs of chromosomes in humans)</td>
<td>Haploid gamete (23 chromosomes in humans)</td>
</tr>
<tr>
<td>Number of divisions</td>
<td>One</td>
<td>Two</td>
</tr>
<tr>
<td>Identical or non-identical cells</td>
<td>Identical</td>
<td>Non-identical</td>
</tr>
<tr>
<td>Used for</td>
<td>Growth and repair</td>
<td>Producing gametes</td>
</tr>
<tr>
<td>Where it occurs</td>
<td>Everywhere except the sex organs</td>
<td>Sex organs (ovaries and testes in mammals)</td>
</tr>
</tbody>
</table>

TIP
Copy out the table headings in the first row and column and test yourself by filling in the rest of the table from memory. This will help you remember the processes.

Show you can...
Explain how you know that a mother’s ova and a father’s sperm are all genetically different.

Advantages of sexual and asexual reproduction

The main advantage of asexual reproduction is the speed at which it occurs and the number of offspring that can be produced. Bacteria can double the size of their colony by binary fission as fast as every 20 minutes. These organisms do not need to find a mate, which can be time-consuming and may involve some form of fighting, which can expend much energy.

The main advantage of sexual reproduction is that it results in genetically different offspring. There are usually fewer offspring when compared with asexual reproduction, however. Producing genetically different offspring leads to genetic variation. This in turn leads to evolution. Variation means that species are far more likely to adapt to any environmental change and much less likely to become extinct.
Tissue culture and taking cuttings

Tissue culture and taking cuttings are techniques that allow farmers or horticulturalists to produce a large number of clones of their parent plant quickly. The process of taking cuttings was described in Figure 13.6. Tissue culture is a form of artificial fragmentation. Small sections of tissue or individual cells are removed from the parent organism. These are then placed into a liquid or jelly growth medium like a broth or agar. This therefore happens in vitro. It allows growth to be easily monitored and the development of the plantlets to occur in sterile conditions.

Test yourself

5 Give the number of parents in asexual reproduction.
6 What is the name given to bacterial reproduction?
7 Describe an advantage of sexual reproduction.
8 Describe an advantage of asexual reproduction.

Show you can...

Explain how plants can reproduce both sexually and asexually.

DNA and the genome

You may hear scientists or people in the media talk about our genetic code. But what does that mean? Specifically what is it a code for? Your genetic code is made from the four ‘letters’ that make up your DNA. The code tells your body how to make proteins. These are a large group of biological molecules that include enzymes and hormones. Your DNA code tells your body how to make these proteins and others, which define your blood group and eye colour, for example. Not all of the variations that make you who you are come from your DNA. Nutrition, scars, tattoos and hair dye, for example, can change your physical appearance without changing your DNA.

DNA is present in the nuclei of almost all of your cells. It is not present in your red blood cells. They are full of haemoglobin to bind to oxygen, which they carry to your respiring cells. Only half of your DNA is present in your sex cells, your sperm or ova. But almost all the other billions of cells in your body have one complete copy of all your DNA. This is called your genome.

Chromosomes and genes

The DNA that makes up one genome would stretch to about 2 m long. To fit this much DNA into the nucleus of one of your microscopic cells it needs to be extremely thin and very carefully coiled up. It is coiled into 23 pairs of structures called...
chromosomes. These come in pairs because you inherit two copies of each chromosome, one from your mother and one from your father. These two copies of each chromosome are different from each other, which makes your genome unique. Unless you are an identical twin, it is highly unlikely that a person has been born with the same genome as you in the past or will be at any time in the future.

Your genome is made from many thousands of genes. Scientists think that there are about 24,000. There are two definitions for a gene. The first is that a gene is a short section of DNA (so part of a chromosome) that controls a characteristic such as blood group or eye colour. This is a simple definition. You now know that a gene is a short section of DNA (so part of a chromosome) that provides the code to make a protein. It is these proteins that really make us who we are.

There are larger areas of your DNA that are not genes. These are called non-coding regions or ‘junk’ DNA. We are still not sure what this DNA does. It might be left over from common ancestors that have evolved differently from us. The amount of non-coding DNA varies between species. Almost all of our DNA is non-coding, at about 98%, while the non-coding regions of many bacteria are about 2%. Their genomes are significantly smaller than ours, however. Forensic scientists are able to detect tiny changes in our non-coding DNA and use them to identify some criminals from evidence taken at crime scenes. This process is called DNA fingerprinting.

The differences in the sequences of DNA that make up all our genes are surprisingly small. Between all the individuals that make up all the humans on Earth there are only about 0.1% of differences. The differences between us and our closest animal relatives, the chimpanzees and bonobos, are about 4%. Human evolution split from that of chimps about six million years ago. In fact we have about half the DNA of our genes in common with the banana plant. These similarities and differences provide evidence for evolution.

**KEY TERMS**

**DNA fingerprinting** The analysis of differences in DNA to identify individuals.

**Evolution** The theory first proposed by Charles Darwin that the different species found today formed as a result of the accumulation of small advantages that were passed through generations.

Figure 14.10 Make sure that you can identify the nucleus, chromosomes and the gene locations on the chromosomes.

Figure 14.11 You have half your DNA in common with a banana and over 95% in common with a chimp.

Test yourself

9 What is a genome?
10 What are the two definitions of a gene?
11 Describe the difference between coding and non-coding DNA.

Show you can...

Explain how DNA makes up a genome.
The DNA of all living organisms on Earth is made from the same four letters. These are A (for adenine), T (for thymine), C (for cytosine) and G (for guanine). The letter A always pairs with the letter T but can be either way around (so A–T or T–A). The same is true of C and G (so C–G or G–C). The letters represent chemical groups called bases and together they are called base pairs. The two sets of base pairs are coiled into a double helix structure shown in Figure 14.12.

The ‘backbone’ of the DNA double helix is made from alternating sugar and phosphate molecules. Attached to every sugar is a DNA base. Each sugar, phosphate and base together are called a nucleotide.

There are over three billion base pairs in your genome. These are separated into the 23 pairs of chromosomes. Chromosomes are numbered by their size. Chromosome 1 is the biggest, with 250 million base pairs, while chromosome 22 is the smallest, with only 51 million. The 23rd pair of chromosomes is called your sex chromosomes and determines whether you are male or female.
The Human Genome Project

The Human Genome Project (HGP) was the world’s largest collaborative scientific project ever undertaken. It started in 1984 and finished in 2003. Twenty universities in the United States, the United Kingdom, Japan, France, Germany and China worked together to identify the sequence of every one of the three billion base pairs from a random male and female volunteer. This is the biological equivalent of going to the Moon! It is stored in its entirety on databases available to us all.

Since its completion scientists have continued to work on identifying where genes begin and end in this sequence of bases. Early benefits of the HGP have been genetic tests that show the likelihood of some illnesses developing, including breast cancer and cystic fibrosis. The future of many medicines and medical treatments is likely to involve the follow-up work to the HGP.

The HGP is an ethical concern for some people. This means that some people disagree with it for religious or moral reasons. Some believe that if individuals’ genomes were public knowledge some employers might be prejudiced against the genetics of those that they employ. Others worry that health insurance companies that know our genetics may charge some people more than others. Is this fair? Would knowing everyone’s genomes make our society better or worse? This is a difficult question to answer.

Test yourself

12 What number are your sex chromosomes?
13 Give the letters for the four bases that make up DNA.
14 Describe why the Human Genome Project is an ethical issue.
15 Describe the advantages of the Human Genome Project.

Protein synthesis

Proteins are important because they affect almost every part of every process within your cells. Enzymes and hormones are proteins. So the speed at which many of your cellular reactions occur is determined by enzymes. As a consequence they affect your metabolism. Your hair and fingernails are made from proteins. Proteins are also extremely important in making your muscles contract and relax.

Proteins don’t last forever and most have a life span of several days. They are then digested by your liver and excreted as urea. Because of this many of your cells are almost continuously undergoing protein synthesis.

Protein synthesis is the formation of proteins. These are made from chains of amino acids, which are linked together in a specific order. They follow the DNA template of a gene. Remember that a gene is a section of DNA from a chromosome that carries the code to make a protein.
Protein synthesis is a two-step process. The first step happens in your nucleus and is called **transcription**. A messenger RNA (mRNA) copy of the coding strand of the DNA is made. An enzyme attaches to the DNA double helix at the beginning of the gene that codes for the protein that is to be made. The enzyme moves along the coding strand of DNA, which unzips and unwinds. The hydrogen bonds between the base pairs break. As the enzyme moves along, the gene makes an opposite copy of the DNA. Opposite a G is a C, and opposite a C is a G. Opposite a T is an A. But opposite an A is a U (not a T). This new strand of mRNA detaches from the coding strand of DNA and exits the nucleus through a pore in its membrane. It finds a special cell component called a ribosome. The enzyme detaches from the DNA, which zips up and returns to its normal double helix shape.

The second step occurs in the ribosome and is called **translation**. Here the opposite copy of the DNA is converted into a protein. Amino acids are joined into a long chain called a polypeptide by **transfer RNA** (tRNA) molecules. Each three bases of the original section of DNA corresponds to one amino acid. This is called the triplet code. There are 64 possible combinations of the four letters that could make up amino acids. In fact all of our proteins are made from about only 20 different amino acids. Often more than one triplet of bases codes for the same amino acid. The polypeptide is then folded into the correct shape to be a protein. This shape allows the protein to complete its function as an enzyme or hormone. Other proteins, including collagen, form structures in your body such as tendons, ligaments and skin.

**What came first?**

Enzymes are proteins and are therefore made during protein synthesis. But protein synthesis requires an enzyme to start. Doesn’t this raise a chicken and ovum situation?! How was the first enzyme ever made?

**Mutations**

Any change to your DNA is called a **mutation**. Mutations can be caused by a number of carcinogenic chemicals such as asbestos and tar in cigarettes, and also by **ionising radiation** such as X-rays and ultraviolet (UV) rays. We tend to think of all mutations as being harmful. Many changes to a person’s DNA will have no effect and some will be positive. Some scientists think that mutations are a driving force in evolution.

Mutations in your DNA can involve swapping (substituting) a base or short sequence of bases. Mutations can also add in new bases or remove them. If a swap occurs then the DNA strand can often still make a protein. If only one base was swapped then a maximum of one amino acid could be different. However, if bases have been added or removed they can alter every amino acid that comes after them during translation. This can have a huge effect on a single cell or organism.
Mutations can alter the shape of the protein being produced. This may mean that the shape of the active site of an enzyme is changed. This may increase enzyme action if the substrate can fit the active site more easily. It may also reduce or stop enzyme action if the substrate cannot easily fit into the active site. Structural proteins such as collagen may become stronger or weaker.

Amino acids on asteroids

The Murchison asteroid fell to Earth in Murchison, Australia in 1969. It is a very large meteorite with a mass of over 100 kg. On it have been found 15 amino acids, including glycine, alanine and glutamic acid. These are commonly found on Earth. Glycine is coded for by the following DNA sequences: GGT, GGC, GGA and GGG. Alanine comes from GCT, GCC, GCA and GCG. The code for glutamic acid is GAA and GAG. Where were these amino acids made? Were they made by life beyond our planet? Or could they simply have been formed without life, perhaps from methane, water and other molecules found in space?

Test yourself

16 What are proteins made from?
17 Describe the difference between a polypeptide and a protein.
18 Describe what the triplet code means.

Show you can...

Explain the process of protein synthesis.

Eye colour

Many characteristics, such as fur colour in mice, red-green colour blindness in humans and our eye colour, are controlled by one set of genes or by a pair of alleles. So you inherit one gene for eye colour from each of your parents. For simplicity we will only talk about blue...
Genetic inheritance and brown eyes here. (You will learn about green eyes beyond GCSE.) We give letters to represent the colours. **Genotypes** are given by letters and **phenotypes** are described in words. So the phenotype is brown eyes and the genotype is the letter that represents that, which is ‘B’. The genotype for the phenotype blue eyes is ‘b’.

You have inherited a gene from each of your parents for eye colour. (You have therefore inherited a pair of alleles for eye colour.) Brown eyes are dominant over blue eyes. So if you have inherited one brown gene from one parent and a blue one from the other, you will have brown eyes. We give the **dominant** genotype a capital letter (see above). So the three possible combinations for eye colour genotype are BB (phenotype: brown eyes), Bb (phenotype: brown eyes because brown is dominant) and bb (phenotype: blue eyes). **Recessive** means the opposite of dominant. We say that blue eyes are recessive to brown eyes. These three possible genotypes also have different terms to describe them. Any genotype that is made from two dominant alleles (BB for example) is called **homozygous dominant**. Any genotype made from two recessive alleles (bb for example) is called **homozygous recessive**. Finally, the genotype made from one dominant and one recessive allele is called **heterozygous**. This is shown in Table 14.2.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
<th>Terminology</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB</td>
<td>Brown eyes</td>
<td>Homozygous dominant</td>
</tr>
<tr>
<td>bb</td>
<td>Blue eyes</td>
<td>Homozygous recessive</td>
</tr>
<tr>
<td>Bb</td>
<td>Brown eyes</td>
<td>Heterozygous</td>
</tr>
</tbody>
</table>

We can see how alleles are inherited if we look at a **Punnett square** diagram. This shape shows the four possible genetic combinations of offspring from two gametes. This will only show inheritance of characteristics that are controlled by one set of genes. Many of our characteristics are controlled by multiple genes working together. You will learn more about this beyond GCSE.

A Punnett square can be used to show the possible genotypic offspring from any two parents. The genotype of one parent is placed above and outside the four boxes. The genotype of the other parent is placed to the left and outside the four boxes. In the example in Figure 14.17, the genotype of the first parent is BB and the second bb. The four possible combinations of genotypes in the offspring are then filled in. You can see that the genotypes for the four possible combinations of offspring are all Bb. This means all offspring from these parents will be heterozygous and will have brown eyes.
Other examples are perhaps more interesting. The Punnett square for two parents with the heterozygous genotype Bb is shown in Figure 14.18.

This means that the couple have a 25% chance of having a homozygous dominant baby with the genotype BB and so brown eyes. They have a 50% chance of having a heterozygous baby with the genotype Bb and so, again, brown eyes. They have a 25% chance of having a homozygous recessive baby with blue eyes. These percentages are often given as proportions. It is easiest to give them as proportions of four. So BB would be one in four, Bb two in four and bb one in four. You will be expected to know about ratios. So a chance of one in four, or one to three, would be written as 1 : 3.

This does not mean that the couple’s first baby will be BB, the second two will be Bb and the fourth will be bb. This means that for each baby, the chances of each genotype occurring are as given above. Think about when you toss a coin. The result is not always alternating heads and tails, but you do have a 50% chance of either each time.

Other inherited characteristics can be shown in the same way using different genotypic letters. Whether the lower part of your ears are attached to your head or you have lobes is controlled by a single gene, given the genotypic letters E/e and whether you can roll your tongue is controlled by a gene given the letters T/t. These are shown in Table 14.3.

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Ear genotype</th>
<th>Ear phenotype</th>
<th>Tongue genotype</th>
<th>Tongue phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homozygous dominant</td>
<td>EE</td>
<td>Free lobes</td>
<td>TT</td>
<td>Can roll</td>
</tr>
<tr>
<td>Homozygous recessive</td>
<td>ee</td>
<td>Attached lobes</td>
<td>tt</td>
<td>Can’t roll</td>
</tr>
<tr>
<td>Heterozygous</td>
<td>Ee</td>
<td>Free lobes</td>
<td>Tt</td>
<td>Can roll</td>
</tr>
</tbody>
</table>

TIPS
- It is important that you can complete a Punnett Square diagram and interpret the results using direct proportions and simple ratios.
- You should remember that most phenotype features are controlled by multiple genes interacting, rather than by one gene alone (as described in this chapter for simplicity).

Hand clapping
Hold your hands down at your side, then clasp them together in front of you. Look down. Which thumb is on top, your left or your right? Try and do it the other way. How does it feel?

Studies on identical twins have shown that hand grasping has some genetic component which is still not fully understood. The same is true of handedness. Globally around 10% of the population is estimated to be left handed but it is still not understood how this complex trait comes about.
It is important that you can construct your own crosses as well as interpret the results of those you are given. You need to be familiar with the key terminology given in Table 14.3 to do this. You might be asked to construct a cross for a homozygous dominant parent and a homozygous recessive parent. The results of this are shown in Figure 14.17. You might also be asked to construct a cross for heterozygous parents. This is shown in Figure 14.20. You might be asked to make predictions for outcomes using probability.

**Family trees**

Family trees can show the inheritance of characteristics over multiple generations. Each generation has its own horizontal line and the oldest are at the top. Men are shown by squares and women are shown by circles. Those with the characteristic are shown coloured in. Two people connected by a horizontal line are parents and their children are shown below them.

![Family Tree Image]

▲ Figure 14.21 Here is the family tree of a family showing the trait ‘inability to roll tongue’.

**Inherited disorders**

Many diseases are caused by pathogens and are transmitted from one individual to another. These are called communicable diseases. Those that we inherit from our parents are called disorders and those people that have them are often described as sufferers.

- **Cystic fibrosis**

  Cystic fibrosis (CF) affects about 10,000 people in the UK. All of these people inherited two copies of a recessive allele from their parents. If an individual inherits the dominant allele from either of their parents...
Parents they will not have CF. Thus all sufferers are homozygous recessive for this disorder. Heterozygous individuals have one copy of this dominant allele and so do not have the disorder. They can, however, pass it to their children. They are called ‘carriers’ for the disorder.

People with CF have excessive mucus produced in their lungs. This often gets infected by bacteria and requires treatment with antibiotics. Physiotherapy helps remove much of the mucus on a weekly basis. However, the mucus stops efficient gas exchange in the sufferer’s lungs. Their ability to exercise is often affected. People with CF sadly have a much reduced life expectancy.

**Polydactyly**

Polydactyly is a genetic disorder that results in babies being born with six fingers or toes. This is a very rare condition. Unlike CF, a person with polydactyly inherits a dominant allele from one or both parents. Polydactyly also appears in cats.

**Test yourself**

23 Give an example of a genetic disorder.
24 What is the genotype for a carrier of cystic fibrosis?
25 Describe the symptoms of cystic fibrosis.
26 Describe the symptoms of polydactyly.

**Show you can...**

Explain how two parents without cystic fibrosis can have a baby that has the disorder.

---

**Sex determination**

You learnt previously that your genome is made from 23 pairs of chromosomes and that you inherited one pair of chromosomes from each of your parents. This means you have two copies of every gene, one from each parent. You also learnt that your 23rd and final pair of chromosomes are called your sex chromosomes, and they determine whether you are male or female.

Gametes are sex cells. Sperm are the male gametes and ova are the female gametes. Each of these cell types was formed during meiosis. This process results in four non-identical daughter cells, which have half the number of chromosomes. This means they only have 23 and not 23 pairs (or 46 in total). They are called haploid (not diploid) because of this. Every one of a sperm or a woman’s ova are slightly different.
If all of a father’s sperm and a mother’s ova were the same the offspring would be clones and each individual's genome would not be unique. During fertilisation a haploid sperm fuses with a haploid ovum. This means the fertilised ovum now has its full 23 pairs of chromosomes again. It is a diploid cell.

Scientists use letters to represent the different sex chromosomes you can inherit from your parents. All ova have an X chromosome. Half of men’s sperm have an X chromosome and the other half have a Y chromosome. If an X ovum is fertilised by an X sperm then the 23rd pair of chromosomes will be XX and the baby will be a girl. If an X ovum is fertilised by a Y sperm then the pair of chromosomes will be XY and the baby will be a boy. Because men produce X and Y sperm in approximately equal numbers, the percentages of male and female humans born on Earth are roughly equal.

The word ‘gender’ has a different scientific meaning from ‘sex’. Your sex is determined by your genetic makeup (your DNA), which in turn controls your sex organs and your secondary sex characteristics. Your gender is determined by your internal awareness of your own personal identification. It is sometimes referred to as the ‘sex of the brain’. Your sex will never change, but increasing numbers of people believe themselves to be a different gender from their sex. People in this situation have a range of medical options available to them.

**Figure 14.24** During fertilisation in humans the sperm and the ovum bring together 23 chromosomes from each parent to form the first cell that goes on to produce a new human being. After fertilisation, this cell has the full number of chromosomes (46).

**Figure 14.25** The 23rd pair of chromosomes determines your sex.

**Show you can...**

- Explain why in terms of fertilisation, it is not surprising that the population of the world is approximately 50% male and 50% female.

**Test yourself**

27 Give the two letters used to represent the sex chromosome in a human male.

28 Give the two letters used to represent the sex chromosome in a human female.

29 Describe how you know that every one of a man’s sperm and a woman’s ova are different.

30 Which letters denote a fertilised female ovum?
Chapter review questions

1. Define the term ‘genome’.
2. Explain why you have two copies of each chromosome.
3. Define the term ‘gene’.
4. Define the term ‘DNA fingerprinting’.
5. Suggest why DNA fingerprinting might be used.
6. Give the four letters that make up DNA.
7. Describe the structure of DNA.
8. Define the term ‘ethical decision’.
9. Give two causes of mutations.
10. Define the term ‘carcinogen’.

11. Explain why we call our DNA our genetic code. What specifically is it a code for?
12. Which types of cell do not have DNA in them?
13. Which type of people have identical genomes?
14. Define the term ‘nucleotide’.
15. Which pair of chromosomes are the sex chromosomes?
16. Describe the major achievement of the Human Genome Project.
17. Explain what collaborative working means.
18. Explain why some people are worried about the information gained from the Human Genome Project.
19. What are proteins made from?
20. Name the organelle in which proteins are produced.
21. Explain why DNA is called a triplet code.
22. Define the term ‘mutation’.
23. Explain why not all mutations are bad.
24. Describe the different types of mutation.

25. Describe the process of taking plant cuttings.
26. Describe how you would extract DNA from a kiwi fruit.
27. Describe an early benefit of the Human Genome Project.
28. Suggest what some future developments of the information from the Human Genome Project might be.
29. Describe the potential effects of a mutation on a protein.
Practice questions

1 In birds, as in humans, chromosomes determine sex. In birds, however, it is due to the inheritance of Z and W chromosomes rather than X and Y. A male bird carries two copies of the Z chromosome and the female bird carries one copy of Z and one copy of W.

a) Copy and complete the sentences below using appropriate key terms.

Birds, like humans, carry out _______ reproduction. The means there is the fusion of separate male and female _______. A benefit of this type of reproduction is that it leads to _______ in the offspring. Male birds have two copies of the Z chromosome, therefore they are described as being _______ whereas female birds have one copy of the Z chromosome and one of the W chromosome and so are described as _______. This is different to humans where males have the genotype _______ and females are XX. [6 marks]

b) Draw a genetic diagram to show the possible sexes produced by mating a male and female bird. [3 marks]

2 a) Flowering plants can reproduce sexually; pollen can be transferred from the male part of the plant to the female part of a different plant. What is the term given to this process? [1 mark]

A Self pollination C Cross pollination
B Self fertilisation D Cross fertilisation

b) Some plants have the ability to reproduce both sexually and asexually. Which two of the following statements are benefits of sexual reproduction rather than asexual reproduction? [2 marks]

A The new plants have all the genetic information of the parent.
B The new plants will be genetically different.
C There is more variation to allow for natural selection.
D More offspring can be produced in a shorter period of time.

3 Coat colour in black mice is controlled by a single gene. There are two alleles for this: the dominant black allele (B) and the recessive white allele (b).

a) What is an allele? [1 mark]

b) Describe the difference between dominant and recessive alleles. [2 marks]

c) What is the probability of a baby mouse having a white coat if two Bb mice are bred? Draw a genetic diagram to explain your answer. [4 marks]

4 Figure 14.26 shows a short section of a single strand of DNA.

a) Where in a human cell is DNA found? [1 mark]

b) i) DNA exists as a molecule made up of two strands. What is the name given to the structure of this molecule? [1 mark]

ii) Using the letters A, C, G and T write down what the sequence of letters would be on the second strand. [1 mark]

4 Figure 14.26

i) What name is given to a short sequence of DNA that codes for a protein? [1 mark]

ii) Explain as fully as possible how DNA can be used to create proteins. [6 marks]

iii) Suppose a mutation occurred in the DNA in the diagram at point X and the DNA base changed from C to T. How many amino acids would be affected by this change? [1 mark]

b) i) What effect could this have on the protein? [1 mark]

ii) Suggest a possible cause of the mutation. [1 mark]

5 a) Cystic fibrosis is an inherited disorder. Which of the following organ systems does it mainly effect? [1 mark]

A Circulatory system C Skeletal system
B Nervous system D Respiratory system

b) Which of the following genotypes would a person with cystic fibrosis most likely have? [1 mark]

A FF C FF
B ff D ff
Writing in science

It is vital that scientists can communicate scientific findings clearly and correctly, both to other members of the scientific community and to the general public. Science communication is often used to inform as wide an audience as possible about research findings or developments, to inform decision making, and to gain support for further study.

The main way that scientists communicate to other scientists is by writing scientific papers, which are published in scientific journals. They also communicate their work and findings through poster presentations.

Science is usually communicated to the general public through the media, whether on news programmes, in newspapers, or on social networking sites. There is a growing demand for scientists to be able to communicate with the public themselves, and most universities encourage outreach programmes where researchers and scientists go into schools and speak to the students and teachers.

Questions

Decide on one of the following titles and produce a piece of writing to allow the general public to understand the science behind it:

- Why have sex? The benefits of sexual reproduction
- Amino acids on asteroids: Did life hitchhike to Earth?
- It is a man’s world – Are sex and gender determined by men?

You will need to research your topic thoroughly, ensuring that you take notes and understand the science yourself to be able to clearly explain it to members of the public.

Make sure you focus on the purpose and audience for your writing. Remember you are writing to inform the general public of a scientific concept, and they may have a limited background in science. You can present your work as a newspaper article, a blog or a presentation. Don’t forget to check your spelling, punctuation and grammar.

A useful tip for helping you structure your writing is to use the Point, Evidence, Explanation writing frame. You might have used this in English or humanities. Using this writing frame for each of your paragraphs will make a point, provide evidence to support it and provide an explanation of how the evidence links to the point, wrapping it all together.
There have been over 100 billion people that have ever lived (with seven billion alive today) and you are the only one to look exactly as you do. So why do no two people look exactly identical? If you are an identical twin, you probably look very similar to your twin but usually people who know you well can tell the difference. These differences are called variations. We can see them in other species too. To many of us all gorillas look very similar but they have differences like us, including separate fingerprints.

This chapter covers specification points 4.6.2.1 to 4.6.2.5 and is called Variation. It covers variation, selective breeding, genetic engineering and cloning.
**Variation**

Variation is the sum of all the small or large differences that make one organism different from another of the same species. So the variation between two cats might include the colour of their fur and their size. Variation is also the sum of the differences between two species. Chimpanzees and bonobos are our closest relatives and so the variation that exists between them and us is less than that between us and plants, for example.

<table>
<thead>
<tr>
<th>Causes of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation can be caused by genetic factors. These include the inheritance of genetic disorders like cystic fibrosis. Other common examples of genetic variation in humans are your eye colour and blood group. Whether you have cystic fibrosis, what your eye colour is and what blood group you are is only determined by the genetics you inherited (your genome).</td>
</tr>
<tr>
<td>Other variation is caused by environmental factors. Your appearance is changed by any scars or tattoos that you have. Your hair colour can be lightened by the Sun. Your skin can be darkened by the Sun, too. All of these examples are not caused by your genetics. They are caused by other factors, which we call environmental.</td>
</tr>
<tr>
<td>A third cause of variation is a combination of genetic and environmental factors (that is, how your genome interacts with the environment). This tends to be more complicated than either genetic or environmental factors alone. Your weight and height are examples of this. People who are born from tall parents are usually tall themselves. There is a genetic tendency for tall people to have tall children. However, we need calcium in our diet for strong bones and teeth. Children who do not receive enough calcium may have shorter bones. Thus your height can be determined by genetic and environmental factors.</td>
</tr>
</tbody>
</table>
**Types of variation**

All variation can be grouped into two types: continuous and discontinuous. All continuous variation comes in a range of values and can have additional values half way between them. Your height is a good example of this. You can be 150 cm or 151 cm tall. In fact you can be 151.5 cm tall. The results of a survey involving continuous variation are shown in a line graph.

Other variation can only fall within certain categories or groups, and there is no grouping in between. This is called discontinuous variation. Good examples of this include blood group and eye colour. You can have type A blood or type O blood but you can’t be halfway between A and O. This doesn’t exist. Similarly, eye colour falls into distinct categories with no groups in between. The results of a survey involving discontinuous variation are shown in a bar chart.

**Normally distributed variation**

The measurement of variation usually involves a survey. Here data are collected from a number of individuals and the relative numbers are recorded and displayed in a line graph or bar chart. A larger survey with more data means that the results are more likely to be reproducible.

Many results of large biological studies looking at variation produce results that are normally distributed. This means that there are a few values at each end of the scale but most come towards the middle. This forms a bell-shaped graph, and we say that this has 'normal' distribution. The more values that are recorded the closer the graph will be to a bell shape. If you did a survey of height in your class at school then you might not find a perfect bell shape. If you surveyed your whole year group you are more likely to find a better bell shape. The point of the graph that has the greatest number is the most common value you have measured while those values at the edges of the bell typically have fewest values. We might call these ‘outliers’.

**Measuring variation**

Two medical students were asked to collect data on the average mass of 11 year olds. Their data are shown in Tables 15.1 and 15.2.

**Questions**

1. Plot the results for student A as a histogram.
2. Do the data show normal distribution?
3. Is the variation continuous or discontinuous?

**Activity**

Table 15.1 Student A’s data

<table>
<thead>
<tr>
<th>Mass in kg</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>35–39</td>
<td>1</td>
</tr>
<tr>
<td>40–44</td>
<td>2</td>
</tr>
<tr>
<td>45–49</td>
<td>4</td>
</tr>
<tr>
<td>50–54</td>
<td>5</td>
</tr>
<tr>
<td>55–59</td>
<td>9</td>
</tr>
<tr>
<td>60–64</td>
<td>6</td>
</tr>
<tr>
<td>65–70</td>
<td>3</td>
</tr>
</tbody>
</table>

**Figure 15.2** Suntans and tattoos are examples of environmental variation.

**Figure 15.3** What examples of genetic and environmental variation can you see in this family?

**Figure 15.4** Bell-shaped graphs show normally distributed data. The most common value is in the very middle and the least common values at each end.


**Mutations**

Any change to your DNA is called a mutation. These occur continuously. On rare occasions mutations give rise to phenotypic variation. If this is suited to an environment, it can lead to relatively quick changes to species in evolutionary terms. Although sometimes mutations can influence phenotype, usually they have no effect on it.

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**Test yourself**

1. Name the two causes of variation.
2. Name the two types of variation.
3. Describe how you would present continuous results.
4. Describe the curve produced by data that is normally distributed.

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**Selective breeding**

For thousands of years before the mechanism of inheritance was understood people have been selectively breeding plants and animals. At its most simple, the principle of selective breeding is that if a big bull is bred with a big cow, then the calves are likely to be big. If this is repeated many, many times then different breeds develop. Selective breeding involves selecting organisms from a population that have a desired variation. These are then bred to produce offspring that share this characteristic.

All dogs belong to the same species (*Canis familiaris*), which is descended from wolves (*Canis lupus*). Selective breeding of big bitches (females) and big dogs (males) has given us large breeds such as the great Dane. Selective breeding of people-friendly and intelligent bitches and dogs has given us breeds such as the golden retriever. Selective breeding of protective bitches and dogs has given us breeds such as the German shepherd. Cats have probably undergone less selective breeding. This is likely to have been because we have bred them for one purpose: to hunt mice and rats.

Jersey cows have been selectively bred to produce creamy milk. They don’t produce much of this, however. Friesian cows have been selectively bred to produce more milk, but it is less creamy. Dwarf
Genetic engineering

Genetic engineering is a modern scientific technique that allows us to move one or more genes from one organism into another. It is also called genetic modification, and the organisms that are produced are called transgenic or genetically modified organisms (GMOs). This is a different process from cloning. Genetic engineering is an ethical issue. This means that some people disagree with it for religious or moral reasons.

Selective breeding is also called artificial selection. This separates it from natural selection, which is the driver in evolution.

Selective breeding can rapidly reduce the variation in a population. This is often called inbreeding and can result in some genetic weaknesses. Repeated inbreeding can magnify some negative characteristics by mistake alongside the desirable ones. Some breeds of dog suffer from these weaknesses, which include misaligned hips (hip dysplasia). This is a genetic condition that can be affected by environmental factors. A ‘gene pool’ is a measure of the total set of genes in a population. There are approximately 10,000 pug dogs in the UK. Because of inbreeding they have a gene pool equivalent to that of only 50 animals. Their genetic variation is very low. This means that they might find it difficult to evolve to a changing environment or combat a new communicable disease.

Test yourself

5 Name an animal other than dogs that has been selectively bred.
6 What is a gene pool?
7 Describe a characteristic in crops that has recently been selectively bred.
8 Describe the problems with inbreeding.

It is important that you can explain the potential benefits and risks of genetic engineering and that some people have ethical objections.

Glow-in-the-dark rabbits

Rabbits do not normally glow in the dark under UV light. Jellyfish do, however, because they possess a gene to make a protein which makes them glow. This gene was cut out from the DNA of a jellyfish using an
enzyme. The same enzyme was then used to cut open the DNA of a rabbit embryo. The jellyfish gene was inserted into the genome of the rabbit embryo and sealed into place using a different enzyme. The embryo was now genetically engineered. It had a gene from a different species in it. It was now a transgenic organism. The embryo was then inserted into the uterus of a rabbit, which from this point onwards had a normal pregnancy. The baby rabbit that was born glowed green under UV light just like the jellyfish.

This was a headline-grabbing example of genetic engineering but not a very useful one. The glow-in-the-dark gene is still used by scientists doing genetic engineering but usually only as a marker to check that other more important genes have been transferred.

Genetically engineered crops

Many plant crops have undergone genetic engineering, usually to improve their yield. An important example of a genetically engineered crop is maize. In many parts of Africa a maize variety that has been genetically modified to be drought tolerant is used. In Europe a genetically engineered form that is resistant to the corn-borer insect is grown. Golden rice has been genetically engineered to contain carotene. This reduces the chance of vitamin A deficiency, which causes blindness. Cotton has been genetically engineered to be resistant to the boll weevil insect pest. Perhaps the most common example of a genetically engineered crop is soya. This has been genetically engineered to be herbicide resistant. This means a herbicide can be sprayed all over it, which will kill weeds in the area but not the soya.

Controversy surrounds the production of genetically engineered crops. Many people think that the technology should be used to help those people who currently do not have enough food. Genetically engineered drought-resistant crops can be planted in parts of the world such as Africa and could save many lives. Other people do not like their use. For some, their religion teaches them that humans should not interfere with God’s creatures. They don’t believe genes should be transferred from one species to another. Others think that the genes might spread into the wild gene pool. What would happen if the gene for herbicide resistance spread to weeds? How would we kill dandelions that are resistant to all herbicides?

Genetically modified animals

Transgenic animals can also be genetically engineered to produce molecules that we need. Sheep have been genetically engineered to produce proteins used in medicine. The blood of people with haemophilia does not clot as quickly as that in other people, meaning that they lose more blood every time they are internally or externally injured. Blood clotting proteins (called factors) have been produced in the milk of genetically engineered sheep and also more recently in genetically modified bacteria.
Cloning

You previously learnt that a clone is the offspring of a parent that has asexually reproduced. When bacteria reproduce by binary fission, yeast cells bud or spider plants produce their plantlets on runners, they produce clones. A clone is genetically identical to its parent organism, but may show differences as a result of environmental variation. All these examples of asexual reproduction produce clones naturally (that is, without human interferences).
Dolly the sheep

In 1996 perhaps the world’s most famous clone, Dolly the sheep, was born. She was the first mammal ever cloned. She was genetically identical to her one parent. This could not have happened naturally. It is for this reason that this remains an ethical issue. This means that some people disagree with it for religious or moral reasons.

Dolly the sheep was formed at the Roslin Institute in Scotland by the English scientist Sir Ian Wilmut (1944–) and his co-workers. He collected one body cell from the udder of the parent sheep. This diploid body cell had two copies of the parent’s chromosomes in it, not just the one found in a haploid gamete. The diploid chromosome number of sheep is 54 which means that all its body cells, including the one taken from the udder, have this number. (This can also be expressed as 27 pairs of chromosomes.)

The nucleus of the diploid body cell with 27 pairs of chromosomes was removed from the udder cell. An ovum cell was removed from the ovaries of a second sheep. The haploid nucleus of this cell was removed to leave behind only the empty ovum cell. This has no trace of any genetic material from the second sheep. It could have been from any sheep. The diploid nucleus from the first parent sheep was then inserted into the empty ovum from the second. This was treated with a small electrical charge to encourage the cell to divide by mitosis. At this point the dividing ball of cells was transplanted into the uterus of a third sheep. Dolly the sheep was born naturally from this surrogate mother.

Dolly the sheep had a pale-coloured face. The ovum cell was taken from a different breed with a black face. The surrogate mother also had a black face. The udder cell nucleus that grew into Dolly was taken from a mother with a pale face. These colours can help us remember that all the DNA came from the one pale-faced parent sheep.

It took 434 attempts before Dolly the sheep was cloned. She lived in Scotland from 1996 to 2003, when she was six. Some scientists think that
Cloning

Dolly died much earlier than normal because of being cloned. In a follow-up study on 70 cloned cows one third also died young. However, scientist Sir Ian Wilmott then showed that Dolly died naturally of an infection of her lungs. This remains a controversial idea, however.

Cloning is a highly regulated scientific process. That means that licences must be granted before it can be undertaken and organisations must follow specific methods and only work on certain organisms. It is currently illegal to clone humans.

Other species

Other species have also been cloned. Before Dolly the sheep scientists had cloned tadpoles (in 1952), carp fish (in 1963) and mice (in 1986). The first large mammal to be cloned was Dolly the sheep (in 1996). Since then rhesus monkeys (in 2000), pigs (also in 2000), cattle (2001) and horses (in 2003) have been cloned. In 2009 the first ever extinct animal, the Pyrenean ibex, was cloned back to life. Sadly the clone only lived for 7 minutes before dying of lung problems and becoming extinct again.

Other forms of cloning

Tissue culture is an example of asexual reproduction. Farmers and horticulturalists take single cells or small pieces of a plant’s tissue and place them into a growth medium. From each cell or small piece of tissue a genetically identical clone is grown. Of course, any environmental variation including light may affect the growth of the cloned offspring.

Embryo transfer and embryo splitting are another common way of creating clones. This is most often used in agriculture for cows and pigs. The process of embryo transfer is shown in Figure 15.13. Here one female is artificially inseminated by one bull. This is therefore an example of artificial selection. Multiple fertilised embryos are collected and then implanted into other females. In addition to this, each embryo can be split into two to give twice as many offspring. This is a little like an artificial way of creating identical twins in humans. It is illegal for this to happen in humans, though.
Cloning plants

Although you can’t clone an animal in the school laboratory, the cloning of plants using a technique called tissue culture is something that you can try.

Method

1. Use a disinfectant solution to wipe down your working area.
2. Using forceps and a scalpel that have been in a sterilising solution, remove a sample piece of tissue from a carrot root or a cauliflower floret.
3. Place the tissue sample in a pot of sterilising solution. Put the lid on the pot and swirl the contents. Continue to swirl the contents every minute for 10 minutes.
4. Use the forceps to remove the tissue sample from the pot. Using aseptic technique, partially lift the lid of a Petri dish containing a nutrient agar with growth hormones and place your sample on the surface. Push gently so part of it sinks in. Close the lid and tape it loosely, but do not seal it.
5. Label your Petri dish with your name and hand to your teacher for incubation under a light bank or on a warm windowsill.
6. After around 10 days you should start seeing new growth and the formation of plantlets from the original tissue sample. Once large enough, these plantlets can be transferred to soil or compost, where they will grow into full sized plants, which are clones of the original plant.

Questions

1. Why was aseptic technique used in this procedure?
2. Which plant hormone could have been added to the agar to stimulate growth?
3. On an industrial scale why do you think this method of tissue culture is sometimes used rather than allowing new plants to be produced through sexual reproduction?

Show you can...

Explain how Dolly the sheep was cloned.

Test yourself

14. How many parents did Dolly the sheep have?
15. Name the term given to an identical genetic copy of another organism.
16. Describe the advantages of embryo splitting.
17. Describe the significance of the facial colour of Dolly the sheep.
Chapter review questions

1. Define the term ‘variation’.
2. Give the two causes of variation.
3. Give an example of genetic variation.
4. Give an example of environmental variation.
5. Define the term ‘genetic engineering’.
6. Explain why Dolly the sheep was a clone.
7. Give an example of variation that is both genetic and environmental.
8. Your hair has become lightened by the Sun. What type of variation is this?
9. Name the two types of variation.
10. Define the term ‘continuous data’.
11. Define the term ‘discontinuous data’.
12. Describe the shape of a graph you might expect if your data were normally distributed.
13. Describe the process of selective breeding using large dogs as an example.
14. Give an example of a farmyard animal that has been selectively bred, and specify the trait that it has been bred for.
15. What is another scientific term that means the same as ‘selective breeding’?
16. Describe the dangers of inbreeding.
17. Define the term ‘transgenic organism’.
18. Explain how scientists genetically engineered a glow-in-the-dark rabbit.
19. Explain how and why golden rice has been genetically engineered.
20. Explain how and why soya has been genetically engineered.
21. Define the term ‘plasmid’.
22. Define the term ‘clone’.
23. Describe how you would use tissue culture to clone plants.
24. Suggest why cats have not been selectively bred into as many breeds as dogs have.
25. Explain why reduced variation in a population is undesirable.
26. Suggest why some people do not like the idea of genetic modification.
27. What substances have been produced in the milk of genetically engineered sheep?
28. Explain how plasmids are used as vectors in genetic engineering.
29. Describe the process of cloning Dolly the sheep.
30. Define the term ‘embryo transfer’.
31. Define the term ‘embryo splitting’.
The bar chart in Figure 15.14 shows information on the blood type of 112 blood donors.

A) i) How many donors were blood type B? [1 mark]
   ii) To the nearest person, what percentage of donors had type O blood? [1 mark]

B) i) What type of variation does the data on blood type show? [1 mark]
   ii) Name the factor that causes variation in blood type. [1 mark]
   iii) Give another feature that is only caused by this factor. [1 mark]

2 The Belgian blue is a breed of cattle that has been kept and bred for over 200 years. The cattle have a natural mutation meaning that Belgian blues have a heavily muscled appearance.

   a) i) What is the name given to the process of breeding particular characteristics into an animal? [1 mark]
   ii) Why do some people disagree with this type of breeding? [1 mark]

b) Describe how the Belgian blue breed was created by farmers. [4 marks]

4 Vitamin A deficiency kills over half a million children under five every year and causes vision problems, including night blindness, for over a million pregnant women. Scientists have genetically engineered a variety of rice called golden rice. It contains several genes from different plants, one of which is the carotene-producing gene from corn, which makes the corn yellow. The means that the rice can be eaten as a source of vitamin A.

   a) What name is given to an organism that contains the genes of a different species? [1 mark]

b) Explain why scientists want to produce golden rice. [1 mark]

   c) i) Use Figure 15.15 to explain how golden rice is produced. [5 marks]
   ii) Some people are concerned with the use of crops produced through genetic engineering. Explain why. [2 marks]
Working scientifically: Dealing with data

Data types and graphs
When carrying out an experiment or investigation, observations are made that lead to the collection of data. Data can come in lots of different forms. One form is numerical, involving numbers that represent an amount and have a unit or are a count of something. This type of data is called quantitative data. Another form is descriptive, involving codes, words or sentences all representing a particular category. This type of data is known as qualitative or categoric data.

Questions
1. Look at the data collected in Figure 15.16 and decide which is qualitative and which is quantitative.

Questions
2. In your class, collect information on the variation seen in eye colour and height in centimetres. Present your data in a suitable table.
When presenting data, we often use graphs as it makes it easier to read the data and find trends. The type of graph drawn depends on the data you have and what you are trying to find out.

### Line graph
This is the most common graph drawn in science. It is used to show how one variable changes with another. It is used when both the independent variable and dependent variable have continuous quantitative data. Data points are first plotted and then a suitable line of best fit is drawn. This is usually a straight line or a curve.

### Scatter graph
This is a graph of plotted points. It is used to explore whether a relationship (correlation) exists between two quantitative variables.

### Bar graph
This is used to show comparisons between categories. The x-axis shows discontinuous data (which can be qualitative or quantitative) and the y-axis shows the continuous data. The bars must not touch as this shows the data are discrete and in their own categories.

### Histogram
This is similar to a bar graph. However, the x-axis in a histogram shows continuous data, not discontinuous data. Because the data are over a range, the bars must touch.

---

**Questions**

3. Draw separate graphs to display your results for the variation of eye colour and height seen in the classroom. Below your graph justify your choice of data presentation.

4. Collect data from 10 students on their hand span and foot length, both in centimetres. Plot a scatter graph of the data and describe the trend seen. Is there any correlation between foot length and hand span?

5. Why was it a good idea to collect the data for foot length in centimetres, not in shoe size?
For much of the history of the human race we have not understood how we and all other organisms appeared on Earth. Many of our ancestors believed that all life was created by an all-powerful supernatural being or beings. Many people alive today still believe this. The theory of evolution explains how the nine million species of life on Earth developed from a common ancestor alive around 3.5 billion years ago. If humans had known this all along, would there be more or fewer religious people today?

This chapter covers specification points 4.6.3.1 to 4.6.3.7 and is called The development of understanding of genetics and evolution. It covers the theory of evolution, speciation, the understanding of genetics and evidence for evolution, including antibiotic-resistant bacteria, fossils and extinction.
The theory of evolution

Evolution is the theory that explains how millions of different species have developed over millions of years from one common ancestor. It explains how changes in inherited characteristics in a population over time may result in a new species through the process of natural selection.

We now have approximately nine million different species of life on Earth. Over two thirds of these are on land. We find some species near the hydrothermal vents at the bottom of the ocean and others can fly over our highest mountains. Evolution explains how organisms have evolved to live in the hottest deserts, the coldest polar regions and everywhere in between. It explains how the organisms that inhabit these places are highly and specifically adapted to live there.

Charles Darwin

Charles Darwin (1809–1882) was an English scientist who is most famous for his work on the theory of evolution by a process he named 'natural selection'. A theory is a rational explanation that can be used to form a hypothesis to test.

In 1831 Darwin set out on HMS Beagle for a round-the-world voyage. During this voyage the ship stopped off at a group of islands off the coast of Chile in the Pacific Ocean to obtain fresh food and water. These were the Galapagos Islands, which were formed from volcano tips that poke from the surface of the ocean. Crucially, these islands have different habitats on them. For example, Baltra Island is very dry, with many prickly pear cacti. Espanola Island has steep cliffs. Fernandina Island is still volcanic and has fresh, black lava flows. These different habitats support many different species of life, including marine iguanas, the blue-footed booby, giant tortoises, and (amazingly) penguins (the Galapagos Islands sit on the equator).
The theory of evolution

During the 5-week stop at the Galapagos, Darwin studied the extensive wildlife. He found groups of mockingbirds that resembled those found on the mainland of Chile. They are now known as Darwin’s finches. Darwin noticed that these birds all had slight differences. Some had long thin beaks, whilst others had larger, stubbier beaks. Darwin spent the rest of the voyage thinking about how these birds developed.

Developing his theory of evolution

Darwin returned to London as a famous scientist, although he did not publish his works on evolution at that point. He was famous for his discovery of new species on his voyage as well as his extensive other work, which included the geology of the continent of South America. Darwin had caught and killed individual birds from the various islands of the Galapagos. He and his colleagues then realised that they were all different species. His theory continued to develop. Later Darwin worked on selective breeding in pigeons. He saw the similarity between this artificial selection determined by humans and what he termed ‘natural selection’ determined by nature. For 15 years Darwin continued to work on his theory in the background while focusing on other species, including barnacles.

In 1858 Darwin had nearly finished writing his theory when he received a paper from a colleague called Alfred Russel Wallace (1823–1913). His work on speciation is described later in this chapter. Wallace’s letter had the effect of prompting Darwin to publish his own theory.

On the Origin of Species

Darwin finally published his book in 1859, called On the Origin of Species. It became very popular. Darwin avoided the potentially difficult issue of human evolution by simply stating “Light will be thrown on the origin of man and his history.” At this time the Church was very powerful and many people believed in creationism. This is where believers simply think that God created the Earth and all life on it. Darwin’s theory therefore had a mixed response. Many religious people thought there was not enough evidence to convince them. After all, the mechanism of inheritance was not known until 50 years after Darwin’s theory was published.

A famous debate occurred in 1860 at the Oxford University Museum. A colleague of Darwin’s called Thomas Huxley (1825–1895) clashed with an English Bishop called Samuel Wilberforce (1805–1873). Wilberforce rudely asked Huxley whether it was through his grandfather or grandmother that he was descended from a monkey. Huxley responded to say that he would not have been ashamed to have a monkey for his ancestor unless it was one who used his great gifts to obscure the truth. This illustrates some of the pressure that existed on Darwin at the time he developed his theory. It may also explain the delay between returning from the Galapagos Islands and finally publishing his work.
The development of understanding of genetics and evolution

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The theory of evolution by natural selection

Darwin wrote “As many more individuals of each species are born than can possibly survive; and as, consequently, there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be naturally selected. From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form.”

This can be summarised in the following way.

- In every population there is usually extensive variation for a characteristic.
- Some variations in some characteristics will mean some individual organisms are better adapted to the environment.
- These will have an advantage and are more likely to survive and reproduce. (This is natural selection.)
- Their offspring are likely to have these same characteristics.
- If this is repeated over many generations new species will be formed.

The new species are so different from the original species they can no longer breed with each other to produce fertile offspring.

This is exactly what Darwin had observed with his finches. He thought that the finches all originally belonged to one species that was probably blown over to the Galapagos Islands from Chile by a storm. Small variations in this original population meant that some birds were better adapted to certain islands. Here they settled. Many generations later the small differences that made the birds settle in the first place have been magnified by evolution and the birds are now different species.

Modelling natural selection

**Method**

1. Use a hole punch to punch 25 paper circles out of a piece of brightly coloured paper and collect the paper discs in a small beaker.
2. Repeat the process using newspaper.
3. Work with a partner. While one of you looks away, the other should spread out the newspaper discs and coloured discs over a sheet of newspaper. Ensure the discs are spread apart.
4. The student who looked away now has 30 seconds to use forceps to pick up as many paper discs as they can. They must pick up the first disc they see and not look for specific colours.
5. Count the number of discs of each colour that you collected and record this number.
6. Repeat the task three more times so a mean can be determined, and then swap over.

**Questions**

1. Present your mean data as a bar graph.
2. Which colour discs did you collect more of? Explain why this was the case.
3. Explain how this can be used to model how evolution through natural selection can occur.
Charles Darwin was sent flowers from an orchid called *Angraecum sesquipedale*. It was an unusual species with an extremely long flower spur, which you can see in Figure 16.7. Darwin suggested in 1862 that this species was pollinated by an unknown moth with a proboscis long enough to reach the nectar at the end of the spur. Just as with his publication of *On the Origin of Species*, Darwin’s ideas were ridiculed by some of his peers. Sadly, it was not until years after his death that the moth was indeed discovered. This species is now known as Darwin’s orchid.

We now know that the moth and the orchid co-evolved. This means that over many, many generations, flowers have evolved longer spurs and the moths have co-evolved proboscises long enough to reach the nectar.

Co-evolution has occurred in a number of other relationships. For example, species of hummingbird pollinate some tropical flowers. The flowers have evolved nectar that the birds can digest and colours that attract them. The hummingbirds have evolved beaks that can fit with the flowers to drink the nectar and simultaneously remove or deposit pollen. Scientists think that this relationship developed in areas without numerous pollinating insects. The plants even produce their flowers at the same time that the hummingbirds breed.

We also see co-evolution in predator and prey relationships. These are clearly very different from the relationships described above. The rough-skinned newt is found in North America. It is eaten by the garter snake. To defend itself the newt has evolved a neurotoxin that concentrates in its skin. Genetic mutations have allowed the snake to evolve resistance to the toxin. In relatively recent times in terms of evolution, the newt has now co-evolved extremely high levels of the toxin in response. This really is an evolutionary arms race.

Jean-Baptiste Lamarck (1744–1829) was a French biologist. He is most famous for his theory of inheritance of acquired characteristics. This is sometimes described as ‘soft inheritance’. Lamarck wrote: “All the acquisitions or losses wrought by nature on individuals, through the influence of the environment in which their race has long been placed, and hence through the influence of the predominant use or permanent disuse of any organ; all these are preserved by reproduction to the new individuals which arise, provided
that the acquired modifications are common to both sexes, or at least to
the individuals which produce the young.” This means that changes that
occur during an individual organism’s lifetime can be passed on to their
offspring. A common example used to support Lamarck’s theory was is
that a giraffe that spends its whole life straining to reach the highest
branches will have a longer neck.

Lamarck could not explain this theory, and it is often discredited. Genes
are the genetic code to make proteins, which determine characteristics.
We now know that genes can be switched on and or off at different
parts of an organism’s life. Some scientists believe that the phenotype
(physical characteristics) of an organism can be altered by their
environment if genes are switched on or off. Perhaps there is a thread
of truth in Lamarck’s theory.

Figure 16.9 Jean-Baptiste Lamarck.
Some scientists are now beginning
to believe some of Lamarck’s theory.

As we have seen, Alfred Russel Wallace was a British naturalist. He
was inspired by Darwin’s travels and in 1848 set off for the Amazon
rainforest in Brazil. He spent 4 years there and then a further 8 years in
what is now Singapore, Malaysia and Indonesia. This was known as the
East Indies in Wallace’s time and also the Malay Archipelago. This region is divided by a narrow
strait of water. Wallace noted key differences
between the species found on either side of the
water. This is now known as the Wallace line.

During this period Wallace developed his own
theory of evolution by natural selection. He wrote
to Darwin describing it in 1858 and their joint
publication occurred a year later. In some regards
Wallace was a little unlucky. He lived at the same
time as Charles Darwin and developed his theory
of evolution by natural selection very shortly after
Darwin. Darwin delayed publication of his work
until he was prompted by Wallace’s communication
to him. Despite this, it is Darwin that most people
remember as the father of evolution.

Wallace’s time in Brazil and the Malay Archipelago
was spent collecting species and other evidence
for his theory of evolution. As part of this he first
discovered that many species use bright colours
as warnings. His work on the separate development of organisms either side of the strait of water provided pioneering work on speciation. This is the gradual formation of new species as a result of evolution. He saw this happen separately either side of the Wallace line. On one side of it is Australia and the other is South East Asia. Wallace looked in particular at the differences in birds on either side of this line. It is worth noting that animals show a better division along this line than plants.

A species is a group of organisms that can interbreed to have fertile offspring. We now know that new species arise as a result of isolation of populations. A famous example of this is the three-spined stickleback fish. During the last ice age a large population of sticklebacks was geographically separated by frozen lakes and rivers. The smaller populations developed in isolation in slightly different environments than those they had adapted to. Their small genetic differences provided variation. Natural selection operated differently in the smaller populations. This magnified the variation over many generations until one of the new populations could no longer interbreed to produce fertile offspring with the other new populations. At this point they became different species. This is speciation.

**Show you can...**

Explain how geographical isolation causes speciation.

**Test yourself**

7. Give an example of an organism that has undergone speciation.
8. Where is the Wallace line?
9. Describe the importance of the Wallace line.
10. Describe why Wallace may be considered unlucky.

**Understanding of genetics**

Gregor Mendel (1822–1884) was a German-speaking scientist and friar. He studied the inheritance of traits in pea plants between 1856 and 1863. Through this work he established rules of inheritance, which are now known as the laws of Mendelian inheritance. You used these laws when you constructed Punnett squares for eye colour, ear lobes and tongue-rolling in Chapter 14. Mendel looked at seven separate characteristics, including the shape and colours of pea pods, flowers and seeds.

He showed that crossing a plant producing yellow peas and a plant producing green peas will always produce a plant that produces yellow peas. This showed yellow to be dominant and green to be recessive. Mendel completed these experiments over several generations and noted the ratios between plant characteristics.

Mendel published his work in 1866, but its significance was not realised until more than 30 years later. At the time of publication his work was rejected because most scientists believed in blended inheritance, in which all characteristics are passed on. Amazingly three separate scientists in three different countries all reproduced Mendel’s work within 2 months in 1900.
Several years later chromosomes were discovered. This was linked closely to Mendel’s work and the idea that the traits that Mendel observed were located on chromosomes. We now know the term ‘trait’ to mean ‘gene’.

Figure 16.12 A flow diagram showing some of the results of Mendel’s investigations into inheritance in pea plants.

Show you can...

Explain how Mendel could have bred a pea plant with yellow seeds from two pea plants with green seeds. (Y is dominant and y is recessive.)

Test yourself

11 Name the founder of modern genetics.
12 Which organisms did Mendel do much of his work with?
13 Describe some of the characteristics that Mendel looked for.
14 Describe why the importance of Mendel’s work was not realised until after his death.

Evidence for evolution

Darwin’s theory of evolution by natural selection is now widely accepted. In the last 200 or so years most criticism of the theory has come from religious groups. Perhaps the largest group are those that believe in creationism. They believe that the Universe and all life within it were created by specific acts of divine creation in seven days. This is one of the main causes of a perceived rift between science and religion. Since Darwin published his theory more evidence for evolution has been discovered, including the relatively new science of genetic mapping of genomes. This evidence is still not sufficient for some believers of creationism.
Evidence for evolution

**Fossils**

Fossils are the remains of organisms from hundreds of thousands to millions of years ago, found preserved in rocks. They are formed in three ways. Some fossils are formed when parts of dead organisms do not decay because the conditions have kept the specimen preserved. Figure 16.13 shows a human body preserved in a **peat** bog. In environments like this there is no oxygen and the water has a low pH. This stops decaying microorganisms from breaking down the body.

Other fossils are formed when parts of the organism are replaced by minerals as they decay. This happens when the organism has been covered with layers of sand, volcanic ash or the silt from the bottom of rivers and seas. The layers above them push down, compressing the organisms. The surrounding water dries, leaving behind mineral salts, which turn to stone. An exceptionally important fossil formed in this way is shown in Figure 16.14. This species is called **Archaeopteryx** and it shows us that reptiles evolved into birds. It has teeth like a reptile but feathers like a bird.

The third way in which fossils are formed is when an organism leaves preserved traces or tracks. These include dinosaur footprints and eggs. Burrows of some organisms have also been found.

**KEY TERM**

**Peat** Partially decayed vegetation.

**KEY TERM**

**Fossil record** All of the fossils that have been discovered so far.

**The fossil record**

The **fossil record** is the information provided by all fossils that have currently been found all over the world. The date of many fossils has to be estimated by looking at the layers of rock in which the fossils are found. Figure 16.15 shows the Grand Canyon in the USA. Because the rocks have been formed by layers of drying sediments, the oldest rocks are found at the bottom of the canyon.
The fossil record shows the gradual evolution of species over time. Some species do not seem to have changed much at all. Figure 16.16 shows the coelacanth fish, which has lobed fins. It was thought to have been extinct for 65 million years until recently, when it was rediscovered by deep-sea fishermen. Figure 16.17 shows fossils of the jaw and skull of an early human ancestor called *Orrorin tugenensis*.

Fossils tell us how much or how little some species have changed over the years. A good example of this is the evolution of the horse. Fossils show that the horse’s hoof evolved over time as a result of the drying of marshes. Originally horses were smaller and had bigger feet to stop them getting stuck in the marshes. As the marshes started to dry up it was the individuals with smaller hooves that had the evolutionary advantage. They could run away from predators faster because they had smaller feet. The fossil record shows this gradual change to smaller hooves.

There are gaps in the fossil record. Not all fossils have been found yet. Many fossils will have been destroyed in hot volcanic lava. In addition, many organisms died and were not preserved. This may be because their bodies were made of soft tissue and not bone. These gaps are slowly being filled in as new fossils are found, but they make it difficult for scientists to be specific about when life first appeared on Earth and how it evolved early on.

**Antibiotic-resistant bacteria**

You have already learnt that evolution is a gradual process that takes multiple generations. In recent years scientists have begun the study of evolution in species that have a much shorter lifespan and so can be seen evolving. This began in the fruit fly *Drosophila melanogaster* in 1980. The fruit fly lives for only about 10 days and so several generations can be studied in a month. Other long-term experiments
Evidence for evolution

look at bacteria, including *Escherichia coli*. One experiment like this is still running and is over 50 000 generations. This kind of study is called experimental evolution.

The development of antibiotic-resistant bacteria also provides evidence for evolution. This is where a mutation arises that makes bacteria resistant to antibiotics. The bacteria carrying the mutation survive antibiotic treatment and reproduce, passing their genetic advantage on to the next generation. Eventually all of the bacteria are resistant to the antibiotics and treatment no longer works. The most common strain of bacteria that has developed resistance to antibiotics is *methicillin-resistant Staphylococcus aureus* (MRSA). Methicillin is a specific antibiotic that is related to Fleming’s penicillin. MRSA bacteria cannot be killed by a range of current antibiotics. Fleming discovered penicillin in 1928, but methicillin was not licensed for use until 1959. Outbreaks of MRSA first started several years later and continue to this day.

MRSA is a communicable pathogen. It is particularly serious in hospital patients. These people often have open wounds that stop their normally effective first line of defence. They may also have a weakened immune system. Sadly people each year die of MRSA that they have caught only after going to hospital. MRSA causes small red bumps on the skin’s surface that develop into large pus-filled boils. Hospitals now encourage the use of antiseptic alcohol treatments to stop MRSA.

The use of antibiotics is currently being tightened. Some people think that in recent years antibiotics have been too readily prescribed by doctors and used in other ways, such as being given to farm animals in their food. This overuse or misuse of antibiotics has helped speed up antibiotic resistance. Many doctors now think that we should not be using so many antibiotics so widely. Perhaps they should not be given to treat non-serious infections such as mild throat infections. It is also extremely important that, if antibiotics are prescribed, a patient takes all the tablets and doesn’t stop as soon as they feel better. Completing the course of antibiotics makes it less likely that resistant bacteria will survive. We have managed to find one new antibiotic in the last 30 years. What happens when a pathogen first becomes resistant to all our antibiotics? The development of new drugs is a slow and expensive procedure and is unlikely to keep up with the emergence of new antibiotic-resistant strains.

### MRSA infection rates

The data in Table 16.1 shows the rate of MRSA infection from 1993 to 2011.

#### Questions

1. Plot the data as a line graph.
2. What is the trend shown by the data? What has happened to infection rates?
3. Why do you think the infection rates changed after 2005?
4. Explain how MRSA-resistant bacteria can arise.

#### Table 16.1

<table>
<thead>
<tr>
<th>Year</th>
<th>Rate of infection per million of the population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>1</td>
</tr>
<tr>
<td>1996</td>
<td>5</td>
</tr>
<tr>
<td>1999</td>
<td>8</td>
</tr>
<tr>
<td>2002</td>
<td>15</td>
</tr>
<tr>
<td>2005</td>
<td>26</td>
</tr>
<tr>
<td>2008</td>
<td>17</td>
</tr>
<tr>
<td>2011</td>
<td>5</td>
</tr>
</tbody>
</table>
Extinction

The theory of evolution explains how organisms that are well adapted to their environment are more likely to reach reproductive maturity, have offspring and pass on these characteristics. The reverse of this is that those organisms or species that are not well adapted are less likely to survive and reproduce. If this continues a species will become extinct (die out). At this point it is extremely unlikely that it will ever be seen again alive. There are approximately nine million species on Earth. Scientists estimate that over 99% of all species that have ever existed on Earth have already become extinct.

The rate at which extinctions occur is increasing together with the increasing numbers of humans on Earth. Our impact on our environment is like that of no other species in our planet's history. We are rapidly cutting down rainforests to plant crops, creating bigger cities and urban areas and will soon be under pressure to drill for oil or other precious materials in some of the world’s most remote places. This will inevitably result in more extinctions.

Extinctions are also increasing as a result of natural changes to the environment over time. For example, the end of the last ice age will have resulted in many extinctions.

The introduction of new predators can also cause extinctions. When Dutch sailors first landed on Mauritius in the Indian Ocean in 1598 they found the flightless dodo bird. This bird had no predators until they arrived. The last dodo was seen in 1662. Even today we do not know for certain what it looked like. Images drawn at the time when it lived vary considerably.

New diseases can cause extinctions. Extinctions can also be caused when a more successful competitor is introduced. This is not always a predator. Introduced species sometimes outcompete existing species for resources such as food or territory.

Approximately 66 million years ago an asteroid hit the east coast of Mexico, making a crater over 110 miles wide. This asteroid was estimated to be over 6 miles wide itself. This forced a super-heated cloud of dust, ash and steam into the sky. Its impact triggered global volcanic eruptions and earthquakes. Sunlight was blocked from the Earth, which cooled its surface. Plants found photosynthesis difficult. Animals further up the food chains based on those plants had less food.
Many species, including the dinosaurs, became extinct. This is called a **mass extinction**.

Volcanic eruptions can have similar devastating effects to asteroid collisions. Many relatively recent mass extinctions, including those 14.5 and 33.9 million years ago, are thought to have been caused by volcanoes. We are currently in the middle of a mass extinction. This is called the Holocene extinction as it is a direct result of the activity of humans. Estimates put the current rate of extinction at up to 140 000 species per year. Most remain unknown.

Humans have managed to remove the smallpox virus from the wild, although it is kept under highly restricted circumstances in some secure laboratories. All viruses are not alive so they cannot be made extinct but the eradication of this virus is a huge achievement. Smallpox killed between 300 and 500 million people in the 20th century. A few scientists in recent years have called for us to attempt extinctions of the one mosquito species that carries malaria. This would save at least a million lives per year. There are many other related species of mosquito that wouldn’t be killed.

**KEY TERM**

**Mass extinction** A large number of extinctions occurring at the same time (humans are the latest cause of a mass extinction).

---

**Test yourself**

19 What percentage of species on Earth are now extinct?
20 Name the species that became extinct on Mauritius in the 17th century.
21 Describe why the extinction of the mosquito may be considered a positive thing.
22 Describe what a mass extinction is and give an example.

---

**Show you can...**

Explain how the dinosaurs became extinct.
Chapter review questions

1. Name the key scientist who developed the theory of evolution.
2. Name the islands that helped that scientist develop the theory of evolution.
3. What animals did Darwin observe on the Galapagos Islands to help develop his theory of evolution?
4. Define the term ‘creationism’.
5. Explain the theory of evolution by natural selection.
6. Define the term ‘speciation’.
7. Define the term ‘species’.
8. Define the term ‘fossil record’.
9. Define the term ‘common ancestor’.
10. Suggest what the common ancestor on Earth may have been like.
11. Define the term ‘natural selection’.
13. Explain how Darwin’s observations of finches led him to develop the theory of evolution.
14. Name the theory that Lamarck developed.
15. Describe an example of Lamarck’s theory.
16. Suggest why Lamarck’s theory has been often discredited.
17. Describe what the Wallace Line is and where it is.
18. Explain the significance of Gregor Mendel’s scientific research.
19. Give the organisms that Mendel used and two traits he looked for in them.
20. Describe how fossils provide evidence for evolution. Give a specific example.
21. Explain why remains are often preserved in peat bogs.
22. Explain why the fossil record is not complete.
23. Define the term ‘mass extinction’.
24. Describe an experiment in which you model natural selection.
25. Suggest why some scientists are now beginning to think that Lamarck’s theory might have some correct science in it.
26. Describe why history has been a little unkind to Alfred Wallace.
27. Explain how the three-spined stickleback is an example of speciation.
28. Explain how the evolution of horses’ hooves is linked to a changing environment.
29. Explain how MRSA bacteria provide evidence for evolution.
Practice questions

1 Figure 16.20 shows a fossil of a small shoal of extinct fish.

a) Define the term 'extinct'. [1 mark]

b) Give two possible causes for the extinction of the fish. [2 marks]

c) Explain how the fossil of the fish could have been formed. [3 marks]

d) Scientists cannot say what colour the fish was. Why is this? [1 mark]

2 Figure 16.21 shows two different species of Porkfish and the part of the world in which they live.

a) Give one apparent difference between the Porkfish species. [1 mark]

b) Explain how the two different species of Porkfish could have developed from an ancestral fish species. [6 marks]

3 Figure 16.22 shows the evolutionary relationship between even-toed hooved mammals.

a) Copy and complete the sentence using one of the words below.

- family
- allopatric
- tree
- map
- time

Figure 16.22 is an evolutionary _____________ . It shows the relationships between different organisms. [1 mark]

b) i) What is meant by a common ancestor? [1 mark]

ii) Which family shown in the diagram is most distantly related to the others? [1 mark]


a) Copy and complete the sentence using one of the words below.

- complex
- adapted
- simple

In this theory Darwin suggested that all species of living things evolved from _____________ life forms. [1 mark]

b) Even though his book was published in 1859 it took many years until the scientific community accepted Darwin’s theories. Which two of the following are reasons why? [2 marks]

A There was not enough evidence
B He wasn’t a published scientist
C No other scientists accepted his ideas
D It went against people’s religious views
The development of ideas

Darwin developed the most accepted theory of evolution by natural selection; however, he did not work in isolation but rather collaborated with many other scientists. Today the scientific community still works together in order to ensure the accuracy of science and to drive research forward. All scientific research is based on theories and hypotheses, which usually come from existing ideas as well as the previous work of others.

There is a long history of research into examining the change in species and the potential causes for those changes. Below are some of the most influential scientists who came before Darwin from a range of scientific disciplines. They all helped to set the foundations for Darwin’s theory of evolution by natural selection.

- Carl Linnaeus (1707–1778) classified living things based on their physical appearance and the way they reproduced. He was the first scientist to suggest that humans showed similarities to primates.
- Georges-Louis Leclerc, Comte de Buffon (1707–1788) was among the first scientists to state that living things changed over time. He also queried the age of the Earth as stated in the Bible – 6000 years old – as he believed evidence showed it to be at least 75,000 years old.
- Jean-Baptiste Chevalier de Lamarck (1744–1829) was the first scientist to publicly state his ideas on why organisms changed over time. His theory that acquired characteristics were inherited was largely discredited – but it is now believed that there may be an element of truth in this.
- Georges Cuvier (1769–1832) supported the theory of catastrophism which supported the argument that natural disasters, such as floods or volcanic eruptions, led to the extinction of species living in affected locations, and that their extinction created space for new species to replace them.
- James Hutton (1726–1797) developed the theory of uniformitarianism. He believed that the Earth was shaped by slow changes over time, not just as a result of abrupt events. He also believed that the changes that shape the Earth today also existed in the past. He therefore concluded that the Earth must be much older than first thought in order to allow for the timescales needed for these changes.

Questions

Choose one of these scientists and use the internet and other sources to research more about their lives and work. Produce a written biography on them, including the following information:

- years of birth and death
- birthplace and place of work
- particular scientific field (geology, biology, mathematics, etc.)
- brief outline of their scientific work
- what work or research they are most known for
- a quote that sums up their research
- any other career they may have had and how this may have influenced their thinking
- how their work benefited Darwin – even if those ideas were later discredited (remember, being wrong is not necessarily a bad thing, as it closes off some areas of research and leads to others).
We are automatically very good at putting things into groups. Before you were able to form memories (usually at the age of three or four) you probably lined up your toys in order of their size, or put them in groups according to their colour or shape. These tendencies continue into later life. Many people collect stickers during childhood, and many adults have collections of objects too. Several hundred years ago we started to find more of the nine million species of life on Earth and scientists started to put them into groups. This is classification.

This chapter covers specification point 4.6.4.1 and is called Classification of living organisms.

It covers traditional binomial classification and modern methods of classification using DNA and RNA technology.
Classification

Carl Linnaeus and binomial classification

Carl Linnaeus (1707–1778) was a Swedish botanist. He is known as the father of modern classification. This is the putting of similar organisms into groups and giving them names. He put them into these groups based upon their structure and characteristics. In 1735 he published an important book called *Systema Naturae* in which he introduced the binomial method of naming organisms. This system gave two names to each organism. In the following years he revised his work until the 12th edition, which was the last he wrote. Throughout these editions his system for classification became more and more detailed.

Only 10,000 species were ever listed in *Systema Naturae*, which is well below the nine million we think exist today. Linnaeus also made appropriate changes between the editions. Whales, which we know today to be mammals, were first classified as fish.

Linnaeus established three large groups of organisms and called them **kingdoms**. These were the animal kingdom, the plant kingdom and the mineral kingdom. He classified organisms within these large groups into ever smaller groups inside them that he called class, order, **genus** and **species**. We no longer use the kingdom for minerals, but the foundations for the animal and plant kingdoms were laid by Linnaeus and are still in use today.

Linnaeus’ use of binomial names is still commonplace today. He put each related group or species of organisms into a larger group with those other species that are similar. He called this a genus (plural genera). So binomial classification gives each organism a two-part name. The first is its genus and the second its species. Our genus is *Homo* and our species *sapiens*. There are currently no other species of human alive, but previously we lived with *Homo erectus* and *Homo neanderthalensis*. Perhaps easier to remember are the five species of the big cat genus *Panthera*. Can you name them? They are *Panthera leo* (lion), *P. tigris* (tiger), *P. onca* (jaguar), *P. pardus* (leopard) and *P. uncia* (snow leopard). Many organisms have their own common name, which may or may not be related to its binomial name. *Leo* is close to lion but *onca* is not like jaguar. There is one organism with the same common and binomial name. Do you know what it is? It is *Boa constrictor*.
Scientists write binomial names in italics with a capital letter only for the genus. We also shorten the genus section of the name to its first letter when we write it subsequently. So *Salmonella enterica* becomes *S. enterica*. As soon as we mention another genus we will need to spell out *Salmonella* in full the first time we use it again.

Since Linnaeus began his work, scientific equipment such as microscopes and techniques such as genome mapping have developed. These technological developments have made classification much easier. We now classify all organisms into five kingdoms. These are animals, plants, fungi, protists and prokaryotes. Remember that viruses are not alive and don’t fit into any of these five. Within these groups are further subgroups that have been finalised since *Systema Naturae*. They are given in the first column of Table 17.1. The rest of the table shows one example of an organism in each kingdom and how it is classified into these groups. The final row shows the common name.

![Figure 17.3](image-url) An evolutionary tree showing relatedness of some animals with backbones. Trace those that have scales.

![Figure 17.4](image-url) This tree is based on DNA similarities.

**Table 17.1** An example of one organism from each kingdom and how they are classified.

<table>
<thead>
<tr>
<th>Kingdom</th>
<th>Animals</th>
<th>Plants</th>
<th>Fungi</th>
<th>Protists</th>
<th>Prokaryotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phylum</td>
<td>Chordates</td>
<td>Angiosperms</td>
<td>Basidomycota</td>
<td>Apicomplexa</td>
<td>Proteobacteria</td>
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<tr>
<td>Class</td>
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<td>Monocots</td>
<td>Agaricmycetes</td>
<td>Aconoidasida</td>
<td>Gammaproteobacteria</td>
</tr>
<tr>
<td>Order</td>
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<td>Asparagales</td>
<td>Agaricales</td>
<td>Haemosporida</td>
<td>Enterobacteriales</td>
</tr>
<tr>
<td>Family</td>
<td>Hominidae</td>
<td>Orchidaceae</td>
<td>Physalaciaceae</td>
<td>Plasmodiidae</td>
<td>Enterobacteriaceae</td>
</tr>
<tr>
<td>Genus</td>
<td>Gorilla</td>
<td>Paphiopedilum</td>
<td>Armillaria</td>
<td>Plasmodium</td>
<td>Escherichia</td>
</tr>
<tr>
<td>Species</td>
<td>Beringei</td>
<td>rothschildianum</td>
<td>solidipes</td>
<td>falciparum</td>
<td>coli</td>
</tr>
<tr>
<td>Common name</td>
<td>Mountain gorilla</td>
<td>Slipper orchid</td>
<td>Honey fungus</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

The relationship between organisms can be shown graphically in a representation a little like a family tree, but over many more generations. Figure 17.3 shows this evolutionary tree for the vertebrates (animals with a backbone). There are five classes: amphibians, mammals, reptiles, birds and fish. Figure 17.4 shows the evolution of humans from other primates. You can see in Table 17.1 that the mountain gorilla also belongs to the primate order.

**TIP**

You do not need to remember the detail in this table. You do need to remember the hierarchy from kingdom to species. Some people remember it by making a sentence from the first letters, such as **Keeping Precious Creatures Organised For Grumpy Scientists.**

**TIP**

You should be able to extract and interpret information from charts, graphs, tables and diagrams such as evolutionary trees.
Other diagrams show the number of species found in each group. Figure 17.5 shows the numbers of vertebrates in each class.

![Figure 17.5 An evolutionary tree drawn showing the relative number of species in the classes of vertebrate.](image)

**Problems with classification**

The definition of a species is a group of organisms that can interbreed to produce fertile offspring. A lion cannot mate with a zebra, so they are different species. A lion can mate with a tiger to produce a liger, but this is infertile. So lions and tigers are different species. Salamanders are an example where this rule fails.

Carl Woese (1928–2012) was an American microbiologist. He pioneered the use of DNA and RNA technology in classification. The results of this are used to further refine classification, and often undo groups based simply on the way organisms look or behave. In particular, Woese looked at a section of ribosomal RNA in a technique called ‘16S ribosomal RNA’. This section of ribosomal RNA has not changed much as a result of evolution.

By looking at RNA in bacteria, Woese was able to refine their classification. He came up with the ‘three domain system’. His three domains are:

1. **Eukaryota** (with all animals, plants, fungi and protists)
2. **Bacteria**
3. **Archaea** (primitive bacteria usually found in extreme environments such as hot springs).
Boloceroides daphneae

In 2006 a new species of marine creature with 2-metre tentacles was discovered in the deep sea (Figure 17.8). Scientists thought that it was a giant sea anemone and it was named Boloceroides daphneae.

Questions

1. Compare the picture of Boloceroides daphneae with another member of the Boloceroides genus shown in Figure 17.9. What features do you think they have in common that led scientists to group them together?

2. In 2014 the American Museum of Natural History examined the DNA of Boloceroides daphneae along with more than 112 species of anemones from the world’s oceans. Their data revealed that Boloceroides was not a sea anemone at all, but instead it classified it as being the first of its own order and it was renamed Relicanthus daphneae.

a) Suggest why scientists prefer to use DNA evidence to classify animals rather than rely on observations of anatomical features.

b) Why is it important that scientists are willing to change their views when new evidence is obtained?

Test yourself

1. Give the hierarchy of classification beginning with kingdom.
2. Describe why ligers do not disrupt the definition of a species.
3. Describe how the three domain system is different from previous classifications.

Show you can...

Explain how vertebrates are classified.
Chapter review questions

1. Describe the process of classification.
2. Define the term ‘species’.
3. Name the five kingdoms we use in classification today.
4. Give the binomial name for humans.
5. Name the diagram in which we can see the relationship between organisms over time.
6. Name the scientist that first developed the binomial system.
7. What are the two groupings of organisms in the binomial system?
8. Define the term ‘kingdom’ in classification and give an example of a kingdom.
9. Describe how scientists write binomial names.
10. Describe the groupings in how scientists now classify organisms.
11. Name a level of hierarchy that includes mammals and reptiles. Give the other three groupings in your answer.
12. Which recent development has allowed us to refine classification?
13. Explain why ligers (half lion, half tiger) do not conflict with our definition of a species.
14. Describe the main grouping of organisms in Linnaeus’ classification.
15. What is the main grouping of organisms in Linnaeus’ classification that we no longer use?
16. Give an example of a mistake made by Linnaeus in his *Systema Naturae*.
17. Name two other species belonging to the *Homo* genus that are now extinct.
18. Explain why we need binomial names for species.
19. Name the scientist who first pioneered the use of DNA and RNA technology in classification.
20. Describe the new system of classification developed by the scientist named in your previous answer.
21. Define the term ‘archaea’.

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Practice questions

1 In 2014 around 18000 new species were discovered and named. One of these was the cartwheeling spider, named for how it moves over the sand dunes in its home environment. As with all species, the cartwheeling spider has a binomial name.

   a) i) Define the term ‘species’.  [2 marks]
   ii) A student wrote down the name cebrennus rechenbergi. What is wrong with how the student did this? [2 marks]
   iii) What does the first word of the binominal name indicate?  [1 mark]

   b) Which scientist is credited with developing the binominal classification system?  [1 mark]

2 Polar bears (Ursus maritimus) and brown bears (Ursus arctos) are related.

   a) Copy and complete Table 17.2 to show how a polar bear and brown bear would be classified.  [8 marks]

   Table 17.2
<table>
<thead>
<tr>
<th>Level of classification</th>
<th>Polar bear</th>
<th>Brown bear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kingdom</td>
<td>Chordata</td>
<td>Chordata</td>
</tr>
<tr>
<td>Class</td>
<td>Mammalia</td>
<td>Mammalia</td>
</tr>
<tr>
<td>Order</td>
<td>Carnivora</td>
<td>Carnivora</td>
</tr>
<tr>
<td>Family</td>
<td>Ursidae</td>
<td>Ursidae</td>
</tr>
<tr>
<td>Species</td>
<td>Ursus</td>
<td>Ursus</td>
</tr>
</tbody>
</table>

   b) Both polar bears and brown bears are mammals. Give two features they have that would classify them as mammals.  [2 marks]

3 Attenborough’s pitcher plant (Nepenthes attenboroughii) is a large plant found on the island of Palawan in the Philippines and is named after the TV presenter and naturalist Sir David Attenborough.

   a) Nepenthes attenboroughii has been classified into the kingdom Plantae, or plants.
      i) What features would be present in its cells that would classify it as a plant?  [2 marks]
      ii) Plants are one of the five kingdoms. Name three others.  [3 marks]

   b) In 1977 Carl Woese proposed a new three domain system based on DNA and RNA evidence to replace the five kingdom model.
      i) What are the three domains he proposed?  [3 marks]
      ii) Discuss why classification systems change over time.  [2 marks]

4 Using Figure 17.11 what is the binominal name for the European otter?  [1 mark]

   a) Canidae
   b) From the diagram, which species is most closely related to the European otter?  [1 mark]
      A Leopard (Panthera pardus)
      B Skunk (Mephitis mephitis)
      C Dog (Canis familiaris)
      D Wolf (Canis lupus)

   c) From the diagram, which is the most distantly related of all the species shown?  [1 mark]
      A Leopard (Panthera pardus)
      B Skunk (Mephitis mephitis)
      C Dog (Canis familiaris)
      D Wolf (Canis lupus)
Working scientifically: Scientific thinking

**Naming conventions**

As you have seen, Carl Linnaeus devised a system of naming organisms. It is called the binomial system because each organism is given a two-part name. The first part of the name refers to the genus that the organism belongs to; it always starts with a capital letter. The second part refers to the species name; it does not have a capital. To make it stand out the binomial name is written in italics, or if handwritten it is underlined.

Today of the nine million species predicted to be alive, 1.9 million have been given a scientific name.

So why bother? One of the issues is due to differences in language, region and knowledge. The same species may go by many different common names, or the same name may be used to refer to several different species. For example, in the UK we think of a daddy longlegs as being a crane fly (Figure 17.11a) but in the USA that common name refers to a harvestman spider (Figure 17.11b).

The cat species in Figure 17.12 is a cougar (*Puma concolor*), but it is also known as a mountain lion, puma or catamount. Having a scientific name avoids confusion, as everyone is clear exactly which organism is being referred to.

### Questions

1. What type of animal do you think the following species names are referring to?
   - (a) *Octopus vulgaris*
   - (b) *Sphyraena barracuda*
   - (c) *Crocdylus niloticus*
   - (d) *Elephas indicus*
   - (e) *Panthera tigris*

2. What about these? Have a guess, and then use the internet to find out the answers.
   - (a) *Hippocampus hippocampus*
   - (b) *Gallus gallas*
   - (c) *Macropus giganteus*
   - (d) *Vulpes vulpes*
   - (e) *Tursiops truncates*

3. Once a new species has been discovered and verified, the scientist who discovered it must select a name and write a description. The name given can be based on a description or the species’ geographical location, or be commemorative (named after a person), or a combination of these.

   Use Table 17.3 to choose an animal genus, and then choose a species name, which describes your organism. Now draw a picture of it based on the descriptions and write its binomial name underneath.

### Table 17.3

<table>
<thead>
<tr>
<th>Animals (genus)</th>
<th>Description (species)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bufo</em> – toad</td>
<td>helix – spiral</td>
</tr>
<tr>
<td><em>Glis</em> – dormouse</td>
<td>lepisma – scale</td>
</tr>
<tr>
<td><em>Taipa</em> – mole</td>
<td>lestes – robber</td>
</tr>
<tr>
<td><em>Apis</em> – bee</td>
<td>salticus – dancer</td>
</tr>
<tr>
<td><em>Lumbricus</em> – worm</td>
<td>satrapes – a ruler</td>
</tr>
<tr>
<td><em>Panthera</em> – large cat</td>
<td>nyctalus – sleepy</td>
</tr>
</tbody>
</table>

▲ Figure 17.11  (a) Tipula oleracea is a daddy longlegs in the UK. (b) Opiliones spp. are called daddy long legs in the USA.

▲ Figure 17.12  Is this a cougar, mountain lion, puma, or catamount?
Adaptations, interdependence and competition

What makes a good rhino? Or what makes a good example of any organism? The answer is the one that is best suited to live in its habitat in a delicate balance alongside the other species there. That would make it the best adapted and most likely to be successful competing with others from its own and other species. So a good rhino will be adapted to live on the grassy plains of Africa together with the lions, zebras and all the other species. If, as is nearly the case with rhinos, they are all hunted then this delicate balance can be quickly destroyed with devastating knock-on effects for other species as well. How long will it be before many species of African mammals are hunted to extinction and what will happen to the other species that live in balance with them?

This chapter covers specification points 4.7.1.1 to 4.7.1.4 and is called Adaptations, interdependence and competition. It covers competition within communities, interdependence and adaptations.
A **population** is the total number of all the organisms of the same species or the same group of species that live in a particular geographical area. The human population is the total number of humans alive. The geographical area for the human population is the entire planet. When talking about the population of big cats in Africa, this would mean all large predatory cats such as the lion and leopard in the entire continent of Africa. A population can be much smaller than this. Some populations have far fewer individuals. Other populations have a much smaller geographical area. Later you will learn about the populations that surround deep-sea thermal vents. These areas are much smaller than Africa!

A **community** is a group of two or more populations of different species that live at the same time in the same geographical area. Populations and their interactions with each other and their environment are studied by ecologists.

**Competition** is the contest between organisms for resources such as food and shelter. Some form of competition exists between all species of life on Earth, including microorganisms. Charles Darwin described this as the ‘struggle for existence’. Competition is the driver for evolution. Without competition evolution slows or stops completely. What biological competition now exists for humans? Are we still evolving?

**Plant competition**

Imagine the death of a mature tree in the rainforest. This might be 30 m tall and form part of the tree canopy. This is the primary layer of the forest, which forms a relatively horizontal ‘roof’. The tree is covered by orchids and other plants that grow on it. Bird species such as parrots and toucans land on its branches. Monkeys swing through them. When this tree dies and falls over, the community changes. Some animals such as the birds and mammals can easily find another tree. But smaller animals find this more difficult. Some small frogs live their entire lives in one small pool of water that is trapped high in a tree’s branches.
As soon as this tree falls a plant race begins. Seedlings that have already germinated and started to grow suddenly speed up their growth. They race for the light above. The gap caused by the old tree falling has provided more light, which means more photosynthesis, which means more growth. Eventually one seedling will avoid being eaten and outgrow the others. In time this will form part of the canopy. Then vines will compete to climb up the newly growing plant. Epiphytes (plants that grow on other plants), including mosses, will compete to grow in the best locations. These may be shady and close to water or in the brighter sunshine. As well as light and space, plants will also compete for water and nutrients from the soil. Many plants have evolved ways of dispersing their seeds far away from the parent plant or plants. This reduces competition between them.

This example is in the rainforest, but competition between plants exists wherever they grow. A similar situation exists in the conifer forests of the Arctic (the region around the north pole), the grass plains of Africa, the hair grass that grows in the Antarctic (the south pole), and everything in between. Competition between two hair grass plants in the Antarctic is an example of intraspecific competition. If it is between a hair grass plant and a pearlwort plant (the only other plant species found there) then it is interspecific competition.

Looking at a woodland
Figure 18.3 shows a woodland in May (a) and July (b).

Questions
1. Look at the photos. What resources are the bluebells competing for?
2. Why do you think bluebells have adapted to flower in early summer before the trees come fully into leaf?
3. Some scientists are concerned that global warming is making trees in woodlands like this come into leaf earlier every year and that bluebells are flowering early to compensate. They are concerned that if bluebells come into flower too early it might lead to them not successfully reproducing. Suggest why you think this is the case.

Animal competition
Animal competition may be easier to observe than in plants. Perhaps it is because it can happen over a shorter timescale. Imagine lions and hyenas on the grassy plains of Africa. Surprisingly, the hyena, which is known as a scavenger of prey caught by lions, actually kills more prey itself. The lions scavenge more hyena kills than vice versa. These two species are competing for food.
Interdependence

**KEY TERM**

**Interdependence** All the organisms in a community depend upon each other and because of this changes to them or their environment can cause unforeseen damage.

Interdependence means that all the species that live in a community depend upon each other. For example, in a marine ecosystem sharks depend upon seals and smaller fish for food. They also depend upon cleaner fish to clean small bits of food from their teeth. The smaller fish depend upon even smaller fish for food. The smallest fish eat zooplankton. These are tiny marine animals that eat phytoplankton for food. Phytoplankton are at the bottom of this feeding relationship, because they photosynthesise. All these different species depend upon each other. Damage to one species will affect others in ways that are very difficult to fully predict.

A stable community is one in which there is much interdependence. That is, all the species are in balance with each other. There are an appropriate number of predators and prey. As the numbers of prey increase, so do the numbers of predators after a short lag phase. As the numbers of predators increase, the number of prey decrease as they are being eaten. Eventually the reduced number of prey means that the numbers of predators will fall.

Now visualise a troop of mountain gorillas. The family is dominated by the alpha male, called a silverback. He is usually the oldest and strongest gorilla and has matured a silver stripe across his back. There may be other male gorillas in the troop. These are almost certainly children of the alpha male. The alpha male will want to mate with all the female gorillas and he will want to stop the other males from doing so in his place.

As well as competing for food and mates, animals often compete for territory. Many of us live in towns or cities, or at least have close neighbours. If a number of people in any one residential area have cats as pets there will be territorial fights. This is particularly fierce between rival male cats. We have found that the territories of domestic cats often change as a result of competition and in many cases overlap.

**Test yourself**

1. Give the term that Darwin gave to competition.
2. Describe how interspecific and intraspecific competition differ.
3. Describe what rival cats might compete for.

**Show you can...**

Explain how and why two seedlings might compete with each other.
Abiotic factors are the non-living parts of the environment. These can be chemical or physical, but not biological.

Light intensity is an important abiotic factor. Because the polar regions are at the poles of our planet they face away from the Sun and therefore they receive a much lower light intensity than the area around the equator. Without this light plants find it particularly difficult to grow in the polar regions. If travelling towards the north pole, you will come to an area where there are no more trees. This is called the tree line. Beyond this point there is not sufficient light intensity to support trees, so none grow.

Other plants require less light. Plants that are used to growing in shady areas like those within the *Hosta* genus usually have big, dark green leaves. They are dark green because they contain lots of chlorophyll and they are big to absorb as much light as possible. If you moved a *Hosta* from the shade into the middle of your lawn it would wilt and die very quickly.

Water is another abiotic factor. Cacti are plants famous for surviving in dry deserts with very high light intensity. Moving a cactus from the desert to a country like the UK would kill it. Our cold winters would not upset a cactus because the nights in deserts can be extremely cold. The excess water would kill the cactus. It would ‘drown’ in too much water. It is often said that more houseplants are killed by overwatering than by underwatering. Many people ‘mist’ the plants in their houses to increase the water content of the air that surrounds them. This is particularly helpful for plants like orchids that have evolved to grow in humid forests.

The pH of the soil and its mineral content are other abiotic factors. Some plants are adapted to live in nutrient-poor soils. Carnivorous plants have evolved to catch insects to supplement the low levels of nutrients in the boggy soils or rocky outcrops they grow upon.
Some plants are very sensitive to soil pH. Species of *Azalea* are known specifically for only growing in acidic soil. Gardeners add peat to their soil to make it more acidic and suitable for these plants.

Farmers spread manure on to their fields and gardeners add compost to their pots to increase the mineral content of their soils. This provides nutrients but also makes the soil more acidic. Farmers often then add lime to reduce the acidity.

Some gardeners cover their soil in lime powder (CaCO₃) to make it more alkaline. This helps plants to absorb major nutrients including phosphorus, potassium and nitrogen, which they need to make proteins. Adding lime to lawns reduces the moss present. It does not kill it directly but moss tends to prefer to grow in soil with a lower pH (more acidic).

Interestingly, the *Hydrangea* plant can grow in both acidic and alkaline soils. Its flowers actually change colour depending upon the type of soil it grows in. If it is found in an acid soil it has pink flowers. If in an alkaline soil its flowers are blue. In this way it acts just like universal indicator paper!

Other abiotic factors that affect a community are wind intensity and direction. Close to the headlands in many coastal regions in the UK are trees found growing at very odd angles and in strange shapes. These have spent their entire lives growing against strong coastal winds. In many cases the strength of the wind has overpowered the ability of their hormones to help them grow towards the light.

A common abiotic factor that affects plants is the level of available carbon dioxide. This is a limiting factor in photosynthesis so plants generally prefer higher levels. Many freshwater aquaria have carbon dioxide bubbled into them to help the aquatic plants photosynthesise.

In a similar way, the dissolved oxygen levels in water act as an abiotic factor affecting the distribution of aquatic animal life. More oxygen means that more life will be able to use it to respire.

### Activity

#### The distribution of lichens

Lichens are made from two organisms (an alga and a fungus) living in a mutually beneficial partnership. They are often found growing on rocks or tree trunks. Design an experiment to compare the distribution of lichens on the north- and south-facing sides of a tree.

### Show you can...

Explain how abiotic factors might affect the growth of a plant.

### Test yourself

8 What are abiotic factors?
9 What do farmers add to their fields to reduce the pH?
10 Describe how the *Hydrangea* plant is unusual.
11 Describe why trees cannot grow beyond the tree line in the Arctic.
Biotic factors

**Biotic factors** are those that are living or related to living organisms. Perhaps the most obvious biotic factor is the amount of food available. The number of populations of organisms in a community depends reasonably heavily on the amount of food available.

- **Introducing predators**
  The introduction of a new predator is a biotic factor that can drastically affect a community. The relationship between predators and prey in a stable community is finely balanced. The numbers of each organism rise and fall in a predator–prey cycle but remain fairly constant within this. If a new predator was introduced into this community the number of prey might reduce extremely quickly. This would also affect other organisms that depend upon either the predator or the prey.

  An example of this is the cane toad. This is native to Central and South America but has spread to Australia and other Pacific and Caribbean islands. In Central and South America it is eaten by several predators, including the broad-snouted caiman, which is like a small crocodile. These, and its other predators, are not found in Australia and the other islands so the cane toad populations have increased massively there. The cane toad is poisonous to the other predators in these regions who, unlike the caiman, have not yet evolved resistance to it. The toad is now an **invasive species** in these areas.

- **Introducing diseases**
  The introduction of new diseases can have devastating effects on populations. Plants, as well as animals, can be infected by pathogens. Dutch elm disease is caused by a fungus that is spread by a species of beetle. This began in Asia and has now spread to Europe. It has killed over 25 million elm trees in the UK alone.

  To try and control the rabbit population in the UK in the 1950s an infection called the myxomatosis virus was introduced. Affected rabbits develop skin tumours and can become blind. They usually die or are eaten by predators within several weeks of catching it. It is spread by direct contact between rabbits but also by mosquitos or fleas. Rabbit populations were purposefully infected by putting sick rabbits into burrows. After 2 years about 95% of the rabbit population had been killed in the UK. Every 2 or 3 years since then, the rabbit population has doubled. It is thought that the new rabbits have evolved a resistance to the disease.

- **Competing species**
  The introduction of one species can simply outcompete another. The red squirrel (Sciurus vulgaris) is native to the UK and Europe. In the UK the numbers of red squirrels have reduced dramatically in recent years. Fewer than 15,000 are left, most of which are in Scotland. In the 1870s the larger
Adaptations

All organisms are adapted to the environment they live in. Without a number of these adaptations any organism finds itself severely disadvantaged against others within its species (intraspecific competition) and other species (interspecific competition). Imagine a rabbit with small ears. It is less likely to hear a predator coming and more likely to be eaten. This means it will be outcompeted by other rabbits with more effective ears. It also means that other herbivores such as deer will outcompete it as well. Adaptations allow organisms to outcompete others and provide them with an evolutionary advantage. Without adaptations and competition, there would be no evolution.

Test yourself

12 Define the term 'biotic factor'.
13 Give an example of a biotic factor.
14 Describe why the numbers of native red squirrels are reducing in the UK.
15 Describe why the introduction of the cane toad to Australia is causing problems.

Show you can...

Explain how biotic factors might affect a herd of zebras.

Adaptations

grey squirrel (Sciurus carolinensis) was introduced. There are now more than two million grey squirrels. This was done on purpose, as grey squirrels were thought to be a fashionable addition to many large country estates. Together with the cutting down of trees, the grey squirrel has caused the massive reduction in numbers of red squirrels in the UK. Because grey squirrels are larger they can store up to four times more fat than red squirrels. This means they are more likely to survive harsh winters. They can also produce more young than red squirrels. Finally, grey squirrels are immune to a pox virus that has killed many entire red squirrel populations.

As a result of the issues described above, the transport of many plants and animals into countries is often illegal or restricted by licences and permits.

Figure 18.13 Look at the adaptations of the thorn bush in this photo. What adaptations do you need to eat thorn bush leaves? A prehensile tongue up to 45 cm long to strip the leaves while avoiding the thorns, and a leathery mouth, allow the giraffe to deal with the plant’s defences.
Adaptations can be structural, behavioural or physiological. **Structural adaptations** are the physical features that allow an organism to compete. Examples include the sharpness of a tiger’s teeth to allow it to kill its prey and the eyesight of a bird of prey to allow it to hunt better. Some animals mimic the structural adaptations of others. Hoverflies have evolved black-and-yellow banding on their body similar to that of wasps. This is shown in Figure 18.14. This type of adaptation is called mimicry.

**TIP**
We describe all adaptations with the advantage they give. ‘A polar bear’s white fur’ is not an adaptation. It is just a simple fact. ‘A polar bear’s white fur camouflages it against the snow, allowing it to hunt more effectively’ is an adaptation.

**Behavioural adaptations** explain how specific behaviours benefit an organism. For example, birds of paradise make their nests extremely pretty or dance in an attractive way to attract a mate. Can you think of the behaviours involved when humans attract their mate? Crows have evolved to use sticks to poke into holes to use as probes to find food. Only a small number of animals have evolved to use tools, including us, other primates, some other mammals including elephants and bears, some birds, reptiles including alligators and crocodiles, fish, octopuses and some insects. Notice that this is a small number but a wide range of organisms that use tools.

**Physiological adaptations** are processes that organisms complete to help them survive. A good example is the production of venom. Many organisms produce venom to deter predators from hunting and killing them. Other animals, including many snakes and some spiders, produce poisons to help them hunt. These can be injected by a bite or a sting. Plants have evolved physiological adaptations by producing poisons as well. *Atropa belladonna* is commonly known as deadly nightshade. If eaten this can kill humans in severe cases. Lilies are poisonous to domestic cats.

Plants produce hormones in their roots and shoots that allow them to turn towards water and light, respectively. This is an example of a physiological adaptation.

**Odd adaptations**
All animals and plants have adaptations to aid survival, but some adaptations are bizarre. Choose one of the following and research how it is adapted to discover its odd adaptation.
- Basilisk lizard (*Basiliscus basiliscus*)
- Treehopper (*Cyphonia clavata*)
- Vampire squid (*Vampyroteuthis infernalis*)
- Pistol shrimp (e.g. *Alpheus bellulus*)
- Toad fish (*Tetractenos hamiltoni*)
- Mimic octopus (*Thaumoctopus mimicus*)

▲ Figure 18.15 A chimpanzee using a small branch as a tool.
Extreme environments

An extreme environment is one that is challenging for most organisms to live within. Imagine somewhere you would find it hard or impossible to live in, and that is probably an extreme environment. These are places that may have highly acidic or alkaline environments. They may be extremely hot or cold. They may not possess much oxygen or water. The majority of the moons and planets in our solar system are extreme environments.

Polar regions

The region around the north pole is called the Arctic. The region around the south pole is the Antarctic. Polar bears are only found in the Arctic and penguins mainly in the Antarctic. Both regions are dominated by their receding polar ice caps. Both regions are obviously very cold. The temperature in Antarctica has reached −89 °C. In the summer of each region the Sun does not set. It is light for the whole day. In the winter the reverse occurs.

Few animals and plants live in the polar regions. In Antarctica perhaps the most famous are the emperor penguins. The male birds look after the eggs on their feet, huddled into a tight circle to keep warm during the cold winter months. This is an example of behavioural and structural adaptation. Polar bears in the Arctic have a small head and ears to reduce heat loss. They have a thick layer of fat (up to 11 cm) under their thick fur to keep warm. Each of these organisms is highly adapted to survive in this extreme environment.

Deep-sea hydrothermal vents

A deep-sea hydrothermal vent is a small gap or fissure on the bottom of the sea or ocean. Here magma from a magma chamber below the sea or ocean bed provides heat. On land these are called hot springs or
geysers. The volcanic activity underneath them releases huge plumes of black or white ‘smoke’ into the water. This is full of dissolved minerals. These precipitate out forming solid chimneys that stretch like stalagmites into the water.

They are under extreme pressure from all the water above them and around them. Their plumes are superheated by the volcanic activity but several metres away the temperature drops to almost freezing. No light can reach the bottom of these vents. Yet life exists here. Any life which exists in an extreme environment, such as the polar regions or around deep-sea vents, is called an extremophile.

We originally thought that all life required light from the Sun. We thought that an organism that photosynthesised was at the beginning of every food web on Earth. Then life was discovered at the bottom of the ocean surrounding hydrothermal vents. Several metres away from the vent there is very little life at all, if any. Bacteria have evolved to feed on the chemicals released by the vents. In particular they feed on sulfur compounds (e.g. hydrogen sulfide), which are toxic to almost all other life.

**KEY TERM**

**Extremophile** An organism that lives in an extreme environment.
Chapter review questions

1. Define the term ‘population’.
2. Define the term ‘community’.
3. Describe what is unusual about the *Hydrangea* plant.
4. What is competition?
5. Define the term ‘alpha male’.
6. Explain what an adaptation is.
7. Name two organisms other than humans that have been observed using tools.
8. Define the term ‘extremophile’.
9. Give two examples of extreme environments.
10. Define the term ‘abiotic factor’.
11. Suggest two abiotic factors that gardeners might be aware of.
12. Describe how gardeners make their soil more acidic.
13. Describe how farmers make their soil less acidic.
14. Describe why farmers add lime to their soil.
15. What is the effect of adding lime to grass? Explain why this occurs.
16. Define the term ‘biotic factor’.
17. Give two examples of biotic factors.
18. What biotic factor often correlates with the amount of food available in a community?
19. Suggest some factors that plants compete for.
20. Suggest some factors that animals compete for.
21. Define the term ‘interdependence’.
22. Describe what happens to individual organisms that are not well adapted.
23. Name the three types of adaptation.
24. Suggest an example of structural adaptation in a shark.
25. Describe mimicry.
26. Explain how hoverflies are an example of a mimic species.
27. Suggest an example of behavioural adaptation in a peacock.
28. Suggest an example of physiological adaptation in a rattlesnake.
29. Describe the behavioural adaptation of male Emperor penguins.
30. Describe how polar bears are adapted to live in the Arctic.
31. Describe the conditions around a deep-sea hydrothermal vent.
32. Explain how light is an abiotic factor.
33. Describe an experiment in which you use pond weed and a lamp to investigate the effects of light on the rate of photosynthesis.
34. Name a plant species that grows in acidic soil.
35. What are the positive and negative effects of adding manure to farmer’s fields?
36. Name the only two plant species that compete at the south pole.
37. Describe the shapes that are seen in a graph of predator–prey cycling.
38. Describe what is unusual about hydrothermal vents.
Practice questions

1 In a rainforest which two of the following would plants most likely compete for? [2 marks]
A Light  C Mineral nutrients
B Water  D Carbon dioxide

2 The native white-clawed crayfish, found in waterways throughout the UK, is currently under threat from a larger and more aggressive invasive species called the American signal crayfish. All crayfish are omnivores and will eat any organic matter they find.

a) i) Name an abiotic factor that could affect the distribution of the white-clawed crayfish in its habitat. [1 mark]
ii) Name two biotic factors that could affect the distribution of the white-clawed crayfish. [2 marks]

b) i) Define the term ‘invasive’. [1 mark]
ii) Explain in as much detail as possible how the introduction of the American signal crayfish could cause the loss of the white-clawed crayfish from British waterways. [2 marks]

3 The red squirrel is a native species and is one of the most threatened of UK mammals. It was once found throughout the UK but has suffered a marked population loss and decline over the last 50 years. In contrast the grey squirrel is an introduced species whose population is increasing throughout the UK.

a) i) Define the term ‘population’. [1 mark]
ii) Suggest two reasons for the decline in the red squirrel population. [2 marks]

b) Table 18.1 gives information on the two species of squirrel. Scientists are concerned that grey squirrels are outcompeting red squirrels.

Table 18.1

<table>
<thead>
<tr>
<th></th>
<th>Red squirrel</th>
<th>Grey squirrel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average body length nose to tail in cm</td>
<td>40</td>
<td>51</td>
</tr>
<tr>
<td>Average mass in g</td>
<td>255–340</td>
<td>396–567</td>
</tr>
<tr>
<td>Breeding habits</td>
<td>Once a year, 1–8 per litter</td>
<td>Twice a year, 1–8 per litter</td>
</tr>
<tr>
<td>Food preferences</td>
<td>Scots pine nuts, Hazelnuts, Spruce cones</td>
<td>Beech mast, Oak acorns, Sycamore seeds, Sweet chestnuts, Scots pine nuts, Hazelnuts, Spruce cones</td>
</tr>
<tr>
<td>Number in UK</td>
<td>160000</td>
<td>2500000</td>
</tr>
</tbody>
</table>

c) Calculate the percentage of squirrels in the UK that are red squirrels. Show your working. [2 marks]
d) Give an adaptation that both squirrels have to living in a forest habitat. [1 mark]

4 Wildebeest are prey animals that are hunted by lions in savannah grasslands. They have several adaptations to avoid being caught.

a) i) Define the term ‘outcompeting’. [1 mark]
ii) What evidence from the table suggests that grey squirrels would outcompete red squirrels? [2 marks]
iii) What is the name for the type of competition between red and grey squirrels? [1 mark]

b) Table 18.1 gives information on the two species of squirrel. Scientists are concerned that grey squirrels are outcompeting red squirrels.

Table 18.1

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<thead>
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c) Calculate the percentage of squirrels in the UK that are red squirrels. Show your working. [2 marks]
d) Give an adaptation that both squirrels have to living in a forest habitat. [1 mark]

5 Finish the graph to show the numbers of Canadian lynxes and snowshoe hares. [3 marks]
Working scientifically: Experimental skills

Emperor penguins have several structural adaptations to allow them to survive in the extreme cold and wind-chill of Antarctica. They have a thick layer of blubber, or fat, under the skin, and outer feathers that interlock to prevent water penetrating their inner feathers, which trap air and insulate them (Figure 18.20).

You are going to carry out an experiment to see whether the huddling behaviour that penguins exhibit is a behavioral adaptation to help emperor penguins keep warm. As you carry out the experiment note down any issues you have with the method or errors that were made.

**Method**

1. Collect 11 test tubes and divide them so you have one on its own, three in a group, and seven in another group, as in Figure 18.21. Use an elastic band to secure each group.

2. Fill the single test tube so it is ¾ full of hot water from a recently boiled kettle.

3. Place the single test tube in a beaker of cold tap water, immediately record the starting temperature and start a stopwatch. Record the temperature of the water in the test tube every minute for the next 10 minutes.

4. Repeat the experiment with the group of three and the group of seven test tube ‘huddles’, ensuring each tube is filled with the same volume of hot water.
Questions

What conclusion can you draw from your data about whether huddling had an effect on the temperature of the tubes?

You are going to write an evaluation for this practical. There are three things that need to be evaluated: the method, the results, and the conclusion. Use the following question prompts to help you write an evaluation of your method. Don’t just answer the questions; instead write your answers in clear paragraphs.

**Evaluating your method**
1. Were there issues with the method or equipment used?
2. Was your experiment a fair test? Were all control variables kept constant?
3. Was the range of independent and dependent measurements sufficient to show a clear trend?
4. How could you improve the method, range or equipment?

**Evaluating the data**
1. How good are your data? Can you identify any anomalous results?
2. If you have anomalous results can you explain what may have caused them?
3. Is there any evidence for random or systematic error in your data? If so can you identify the cause?
4. Is your data repeatable or reproducible? If not, what could you have done to ensure it was?

**Evaluating your conclusion**
1. Did your results show a clear trend?
2. Is there enough evidence to support your conclusion?
3. What are the areas of weakness in your method or data that make you less sure of your conclusion? What could be done to reduce these?
4. What further evidence is needed to fully support your conclusion?
You are made from thousands of billions of cells. Each of these is made from millions of billions of atoms. These numbers are probably too big for most of us to understand. Many of these atoms are carbon, which forms a ‘cellular skeleton’ for all life on Earth. The carbon atoms in your cells were not always yours. They are recycled when we die and form other living or non-living substances. When you die some of your carbon atoms might make up carbon dioxide, some might be trapped in chalk rock, others might become a part of animals or plants. Scientists estimate that each of us has some of the carbon atoms that once made up William Shakespeare (or any other long dead person you might prefer). How many of your carbon atoms came from Charles Darwin?

This chapter covers specification points 4.7.2.1 to 4.7.2.4 and is called Organisation of an ecosystem. It covers levels of organisation, the carbon and water cycles, decomposition and the impact of environmental change.
Levels of organisation

An ecosystem is a community of living organisms in their environment. A community is a group of two or more populations of different species living at the same time in the same place. A population is the total number of organisms of the same species or similar species that live in the same place.

Sampling

Sampling is a process by which scientists look at a part of a habitat and draw conclusions about the whole of it. For example, if you wanted to know whether polar bears were becoming less common, you could either count them all or you could count a smaller but representative sample of them and make judgements using these data alone. Counting them all will take too long and might mean that the numbers had changed by the time you thought you had finished counting.

Quadrats

Quadrats are used in many forms of sampling. A quadrat is simply a square of wire or wood frame that is placed on the ground and the organisms that are within it are recorded. This is obviously most useful for plants or small, static or slow-moving animal species. Often 0.25 m² quadrats are used. If you were looking to sample large organisms such as bushes or shrubs you would definitely use quadrats that are much bigger than this.

The recording of organisms happens in one of three ways. Sometimes the number of individual organisms is counted. If you wanted to see whether there were more daisies or dandelions, you would have to count them both. Other times the number of different species is counted. This gives you an indication of how biodiverse an area is. Finally the percentage cover of a plant is recorded. This is an estimation of the percentage of your quadrat that is covered (by grass, for example).
Random sampling using quadrats

Imagine that you are trying to estimate the number of daisy plants in a field. It is common mistake to think that you stand in one place, close your eyes, spin around, throw your quadrat and sample where it lands. How often is it likely to land at your feet? How often is it likely to land beyond the reach of your throw? It never will. Most of the sampling that we do involves the random placing of the quadrat. This is important to remove all forms of bias from your results.

So you choose a fixed location from where you will always start. It is usually the corner of the field or area. From here you use a pair of random numbers from a table in a book or the internet as coordinates. The first random number tells you how far to walk forwards. You then turn to one side and the second random number tells you how far to walk in that direction. It is here that you put your quadrat down and count the daisies in it. You then move back to the start and repeat using the next two random numbers.

If you just completed two 0.25 m² quadrats you would not be able to make appropriate conclusions about the number of daisies in the field. Sampling must be representative. If you wanted to find out about the whole population of red squirrels in the UK you couldn’t just look at those in one small part of England. About 85% of the red squirrels in the UK are found in Scotland. So if you just sampled a small part of England and used the number there to make estimates about the number in the whole of the UK your estimate would be far too low. If you looked at the number in Scotland and tried to make estimates they would be too high.

Scientists often look for three concordant results in experiments. Observing these makes us confident that the results are reliable. However, in ecological studies the number of samples increases massively so that a representative sample is taken. So you may have to complete 50 quadrats to get a representative sample of the field. The more quadrats you sample the more confident you can be in your results, but the longer it will take.

After you have completed as many quadrats as you can, you calculate an average per quadrat. You then measure the area of the field. Next you work out how many quadrats fit into it. If you know that 250 quadrats fit into the whole field and that you have found an average of three daisies per quadrat, you multiply the numbers to estimate the total number in the field.
This sort of sampling is often used to compare the number of organisms in two different areas. If you wanted to find out whether there were more dandelions in sunny parts of the field, you would divide it into sunny and shady areas. You would repeat the process just described in these two separate areas and compare the results.

**Systematic sampling using quadrats**

There is another method of using quadrats, called systematic sampling. Instead of randomly placing your quadrat you would place it in a systematic (or regular) way. You would do this only when you wanted to check whether the distribution of an organism changed in an area. Imagine you are on a rocky seashore. You could try random sampling to estimate the total number of crabs on the seashore. You would do this using random numbers as described in the first part of the previous section. If you wanted to look at whether there was more seaweed above or below the waterline you would do this using random numbers in both areas.

However, if you want to look in more detail at how seaweed is distributed on the seashore you could use systematic sampling. Here you would draw a line called a **transect** from the top of the shore to the bottom. You would systematically place your quadrat on this line, say every metre, and record the number of seaweed species.

Scientists often record abiotic factors along transects to compare their biological data with. This helps them draw conclusions about why the organisms are distributed the way they are along a transect.

The type of sampling you undertake depends upon the question you are trying to answer. Is it just an estimation of a population? If so, then you will place the quadrats using random numbers. Is it comparing the numbers of organisms in two areas? If so, then you will place the quadrats using random numbers separately within these areas. Or are you trying to see how the distribution of an organism changes with differences in the habitat? If so, then you will place the quadrats systematically along a transect.

**Test yourself**

1. Name the square device that is often used in sampling.
2. Name the line upon which you might sample.
3. Describe why it is necessary to sample habitats.
4. Describe how you would place a quadrat in random sampling.

**Show you can...**

Explain when you would use random and when you would use systematic sampling.
19 Organisation of an ecosystem

Measure the population size of a common species in a habitat. Use sampling techniques to investigate the effect of a factor on the distribution of this species.

This practical has two parts. First you will work out an estimation for the population size of a species in a given area and then you will investigate how an abiotic factor affects its distribution within this area.

**Part 1: method**

1. When you are given a quadrat the first thing you need to do is to work out the area of your quadrat in m². It is likely that you have been given either a 1 m quadrat or a 0.5 m quadrat.

   \[
   \text{area} = \text{length} \times \text{width}
   \]

   **Example**
   - For a 1 m quadrat:
     \[
     \text{area} = 1 \times 1, \text{ so the area is } 1 \text{ m}^2
     \]
   - For a 0.5 m quadrat:
     \[
     \text{area} = 0.5 \times 0.5, \text{ so the area is } 0.25 \text{ m}^2
     \]

2. Using your method of random sampling, find your first sampling point and place the quadrat down. Determine either the number or the percentage cover of your chosen plant in your first quadrat. If some plants are half inside the quadrat, remember to only class the plants on two sides of the quadrat as being in and the plants on the other two sides as being out (Figure 19.4).

3. Repeat this process for the remaining nine quadrats.

4. Determine a mean for the plant you studied across all your quadrats. If you had a 1 m² do this by adding up all your data and dividing by 10. If you had a 0.5 m² quadrat you need to do the same but then multiply your final answer by 4 to give your estimation of plants per m².

5. Your teacher will provide you with the approximate area for the total site studied. Use this to estimate the abundance of the plant across the site (total area m² × average abundance of plant = abundance of plants per m²).

   **Example**
   - Using the data in Table 19.1:
     \[
     \text{area} = 5060 \text{ m}^2
     \]
   - So you can estimate that there are:
     \[
     8.6 \times 5060 = 43516 \text{ daisies}
     \]
Levels of organisation

6 Repeat the process by taking 10 more random samples.
   a) What did this do to your mean?
   b) How did this change your estimation for the abundance of your chosen plant on the field?

7 Combine all your class data and use this to determine a mean abundance of the plant per m² for your class. Use this to estimate the abundance of the plant across the site.
   a) Why does taking more samples lead to a more valid estimation?
   b) Why do you think when ecologists are measuring abundance they usually only measure at most 10% of the area?

Part 2: method
1 Your teacher will tell you which abiotic factor you will be studying, the length of the transect and the distance between your quadrat sampling points.
2 Within the chosen habitat, identify a sampling site that shows variation in the abiotic factor being studied. Position a tape measure to guide your transect.
3 Starting at the 0 m end of the tape, lay your quadrat down so that the left-hand bottom corner is level with the 0 m mark. Identify the abundance of your chosen species within the quadrat and record in a suitable table, as in Table 19.2.

<table>
<thead>
<tr>
<th>Distance in metres</th>
<th>Abundance of grass in %</th>
<th>Light intensity in arbitrary units</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>53</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>74</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>9</td>
</tr>
</tbody>
</table>

4 Measure and record the abiotic value for the quadrat.
5 Move the quadrat to the next sampling point and determine and record the abundance of the species and record the value for the abiotic factor.
6 Repeat this until you reach the end of the transect.

Questions
1 Describe how the abundance of your chosen species changed as the abiotic factor changed.
2 Suggest a reason to explain the difference in abundance.
3 Why could you be more confident that you had a valid trend if you had carried out four more transects?
Producers, consumers and decomposers

There are three ways in which organisms obtain the energy store they need to live. They can produce the energy store they need. They can consume other living organisms that have already produced this energy store. Or they can obtain it from the bodies of dead organisms.

**Producers**

Anything that photosynthesises is a **producer**. It is able to ‘produce’ its own energy. Many scientists don’t like the term ‘producer’ because no energy is ever produced except by stars. All energy is converted from one form to another. But they are called ‘producers’ not ‘converters’! It is often helpful to remember that they produce **biomass** (living tissue) from **inorganic** compounds.

All plants photosynthesise. They harness the energy from the Sun transferred by light and convert it into chemical energy stored in glucose. Algae can photosynthesise too. In fact, about 70% of the oxygen made each day by photosynthesis comes from photosynthetic algae and not plants.

Photosynthesising plants and algae are the only organisms on Earth that are able to use the energy transferred from the Sun in this way. Surprisingly they can only use (or capture) about 1% of the energy from light. Even though this does not sound like very efficient energy transfer, almost all life on Earth is dependent upon this.

There are some organisms that get their energy from a source other than the Sun. Can you remember where they were? They are called extremophile bacteria and they are found near hydrothermal deep-sea vents. They feed directly on the chemicals released by the volcanic activity immediately below the vent. Because these vents are on the ocean floor no light will ever reach them. No life could survive there that depended upon sunlight.

**Consumers**

Any organism that obtains its energy by eating another is a **consumer**. These are usually animals but can also be microorganisms. One group of consumers are herbivores. Any animal that eats any plant (not just herbs) is a herbivore. Common examples are sheep and rabbits. Only 10% of the energy that is found in the grass is passed to the herbivore.
Producers, consumers and decomposers

Figure 19.6 The energy use of a cow. Compare the food energy eaten with the amount built into body tissue. Look at the large amount of energy left in the faeces. What organisms can use this?

<table>
<thead>
<tr>
<th>grass eaten</th>
<th>100 J</th>
</tr>
</thead>
<tbody>
<tr>
<td>urine</td>
<td></td>
</tr>
<tr>
<td>tissues</td>
<td>4 J</td>
</tr>
<tr>
<td>respiration</td>
<td>33 J</td>
</tr>
<tr>
<td>faeces</td>
<td>63 J</td>
</tr>
</tbody>
</table>

A second group of consumers are carnivores. These are any animals that eat meat, either from herbivores or from other carnivores. Examples are lions and sharks. A predator is any animal that hunts and kills prey for food. Only about 10% of the energy found in the producer (or consumer) reaches the consumer that eats it. Omnivores are animals such as rats, bears and most humans.

Decomposers

A decomposer is any organism that breaks down the remains of a dead organism. This breakdown is called decomposition, or rotting. Bacteria are very important decomposers. They exist in very high numbers in soil. In one gram (the mass of a jelly bean) there are often over 40 million bacterial cells. Three types of bacteria play a very important role in the natural cycling of nitrogen. This element is of specific importance because it is needed to make proteins.

Fungi are also decomposers. We often see them growing on rotting tree trunks in forests or compost heaps. Fungi break down organisms by releasing digestive enzymes onto the material (often wood). Shortly afterwards they will absorb the nutrients from the broken down cells by diffusion. This is obviously not the same as taking in food as we do and excreting that which we don’t need.

Gardeners try to provide perfect conditions for rapid decay on compost heaps so they can then add the compost produced to their garden. Compost is a natural fertiliser.

If decay occurs in anaerobic conditions, methane gas is produced. This often happens in purpose-built biogas generators, which produce methane to be used as a fuel.

KEY TERM

Omnivore An organism that eats both plants and meat.

Figure 19.7 Earthworms are decomposers.

Test yourself

5 Give an example of a decomposer.
6 Give an example of an aquatic producer.
Materials cycling

The carbon cycle

Carbon is the key element for all known life. The complex molecules that make up all life (such as proteins) are made when carbon chemically bonds with other elements, especially oxygen, nitrogen and hydrogen. Each carbon atom is able to make four single bonds. This is more than many elements and may be the reason why all life on Earth is based on carbon. Many scientists think that when we find extra-terrestrial life it will also be based on carbon.

A carbon atom can change over time. It can bond with two oxygen atoms to form carbon dioxide. It can be bound to another five carbon atoms, twelve hydrogen atoms and six oxygen atoms to form glucose. It can bond with four hydrogen atoms to form methane. These are three key substances in the carbon cycle but it can bond with different elements to form countless different compounds.

The carbon cycle is shown in Figure 19.8. It can be simplified into four separate processes called photosynthesis, respiration, combustion and decay.

The equation for photosynthesis is:

\[
\text{light} \quad \text{carbon dioxide and water} \rightarrow \text{glucose and oxygen}
\]

Carbon is converted from the carbon in carbon dioxide to the carbon in glucose.

The equation for respiration is:

\[
\text{energy} \quad \text{glucose and oxygen} \rightarrow \text{carbon dioxide and water}
\]

So the conversion here is between carbon in glucose and carbon in carbon dioxide.

**Combustion** is the release of energy from burning a fuel. The reaction for burning natural gas (like when you light a Bunsen burner) is:

\[
\text{energy} \quad \text{methane and oxygen} \rightarrow \text{carbon dioxide and water}
\]

So the conversion here is between carbon in methane and carbon in carbon dioxide. The percentage of carbon dioxide in the atmosphere is 0.04%. This sounds very low but is the highest it has been in 800000 years.
Decay occurs when a living organism is broken down by decomposing bacteria and fungi. These organisms help biological material decompose. When plants die and rot they release their carbon back into the atmosphere as carbon dioxide waste from the respiration of decomposing microorganisms. The carbon was incorporated into their tissue when they photosynthesised. When animals die and rot they release carbon dioxide into the atmosphere, and they also release mineral ions back to the soil.

Test yourself

7 Name a key process in the carbon cycle.
8 What is the percentage of carbon dioxide in the atmosphere?
9 Describe the conversion of carbon during combustion.
10 Describe the conversion of carbon during respiration.

Show you can...

Explain the processes by which carbon is cycled.

The water cycle

Water is the major liquid component of all cells and therefore all life. It is perhaps shocking, then, that over a billion people do not have suitable access to safe fresh water. Water covers 71% of the Earth’s surface. Over 95% of it is found in our oceans and seas and is therefore mixed with salt. The rest is found as freshwater on land, in glaciers and in the polar ice caps. A very small amount (0.001%) is found in the air as clouds and rain.

We find water on, above and below the surface of the Earth. It can exist as a solid in the polar ice caps, a liquid in the oceans and a gas as the water vapour you breathe out. The movement of water from one place to another and from one state of matter to another is called the water cycle. The water cycle is shown in Figure 19.10 on the next page. It can be simplified into six separate main processes called precipitation, runoff, infiltration, subsurface flow, evaporation, and transpiration. Water is constantly moving as a result of these processes.

Precipitation is the scientific name for rain. This obviously occurs when condensed water vapour falls to the surface of our planet. Precipitation is therefore preceded by condensation. Snow, hail and sleet are all types of precipitation too. Interestingly more than three quarters of the precipitation on Earth falls over our oceans.

Runoff is a term that describes the movement of water across any type of land. Imagine water running down mountain streams. This is runoff. It typically runs from smaller streams into rivers and then lakes, and finally the sea or ocean. Much of the runoff water is used by farmers for agricultural purposes.
Infiltration is the movement of water from the surface into the ground to become groundwater. Areas such as the Peak District, South Wales and the Mendip Hills have aquifers. These are underground layers of rock that are permeable to water. So water is naturally stored in these rocks. Runoff water can sink through these rocks by infiltration and is stored in aquifers. As well as being stored, water in aquifers can move towards the ocean or back to the surface as a natural spring. This is called subsurface flow.

Evaporation is the process by which water turns from a liquid to a gas. This change of state requires energy, which usually comes from the Sun. Water can evaporate from all water courses, including oceans, seas, lakes and ponds.

Transpiration is the evaporation from its leaves of up to 90% of the water a plant takes in through its roots. Here water is absorbed into a plant as a liquid before being released into the atmosphere as a gas.

Explain the processes in the water cycle.
Show you can...

11 Name a process in the water cycle.
12 What percentage of the Earth's water is found in the oceans?
13 Describe the process of infiltration.
14 Describe the different types of precipitation.

Decomposition

Decomposition, or decay, is the breakdown of once-living organisms into much smaller substances. This process is essential to recycle the basic compounds, such as amino acids, that are needed for other life to grow. Decomposition almost always begins immediately after death and is primarily by the growth of fungi and bacteria.
Investigate the effect of temperature on the rate of decay of fresh milk by measuring pH change

In this practical you will investigate how temperature affects the rate of decay of milk.

Method

1. Your teacher will tell you the four temperatures that you will be investigating. Clearly label four beakers with these temperatures.
2. Into each beaker add 25 cm$^3$ of fresh milk.
3. Using Universal indicator paper, determine the pH of the sample and record in a table.
4. Cover each beaker with clingfilm and leave for 3–5 days at the required temperature.
5. Carefully peel back a little of the clingfilm on each beaker and add one drop of Universal indicator to determine the pH. You may need to allow your freezer sample to thaw slightly before doing this.
6. Determine a change in pH for each milk sample.
7. Samples must be autoclaved before disposal.

As milk decays, its pH changes. This is because as the lipid (fat) molecules in the milk decay, they break down in the glycerol and fatty acids. There are also bacteria in milk that carry out a chemical process to provide them with energy by reacting with the sugar in milk (lactose) and oxygen to make lactic acid.
Impact of environmental change on distribution of organisms

The distribution of organisms in any environment depends upon a large number of factors. In fact, many of these factors interact with each other, so it can be quite difficult to work out exactly why organisms are distributed the way they are. Some of the key factors are described below.

- **Water**

  No life can exist without water. The amount of water in an ecosystem is therefore a very important part of where organisms are found. Deserts have very little water. In many deserts it has not rained for many years. Despite this we see some life there. The animals and plants that can survive in deserts are highly adapted to do so. Cacti have spines for leaves to minimise water loss through transpiration. Many animals, including camels, have also evolved to reduce water loss. They do this by absorbing as much water as possible from their food and concentrating their urine. In some deserts water rises from underground sources. These are called oases. They are not always permanent, and in fact some are thought to have dried up as a result of human interference. More life is found surrounding oases than elsewhere in deserts.
Rocky seashores in temperate regions are another interesting place to see the importance of water, this time for algae. At low tide you can often see different species of seaweed growing in very distinct horizontal regions across the shore. Towards the top of the seashore (so out of the water much of the time) several species from the *Fucus* genus are found. At low tide (so submerged for most of the time) are kelps (*Laminaria* species). Scientists have swapped species from different regions and seen that they quickly die. These species have evolved to grow in the specific regions of the shore, which have the correct amount of time above and below the tide.

Some organisms that are present or absent in water can tell us about its pollution levels. Because they are living we call them *bioindicators*. Examples of bioindicators are shown in Figure 19.15.

---

**Impact of environmental change on distribution of organisms**

**KEY TERM**

**Bioindicator** An organism whose presence or absence tells you about the cleanliness of an ecosystem.

---

**Temperature**

Temperature also plays a very important role in the distribution of organisms. Imagine swapping habitats for a polar bear and a camel. How long do you think they would survive? Deserts are also a good example of an environment with huge ranges in temperature. In many deserts the temperature in the daytime can reach 45°C and fall below freezing at night. Many animals, such as meerkats, avoid the heat of the afternoon and the cold of the night by sheltering in burrows or shade. Thus, much of their activity is in the early morning or late afternoon.

**Global warming** is the gradual increase in temperature as a result of the greenhouse effect. One consequence of this is species migration away from the equator. Any increase in temperature will mean that organisms will move northwards or southwards to find temperatures that they have evolved to live in. There is currently little or no malaria in the UK. This is primarily because the temperature is too low for mosquitoes to survive and spread the disease. If global warming continues, how long will it be before the temperature in the UK has increased to those found in the tropics? At this point mosquitoes will...
be able to survive in the UK and the levels of malaria are likely to increase.

Changes in temperature caused by seasons trigger huge changes in animal distribution. These are called migrations. Swallows, swifts and many other birds migrate from Northern Europe to North Africa. The Arctic tern is well known for its migration from its breeding grounds in the Arctic to the Antarctic each year. This gives it two summers each year, but it must fly approximately 12 000 miles. Fish also migrate. Many, such as salmon, do this to breed. They are born in freshwater rivers, migrate to the sea to live and return to freshwater to reproduce. Many in fact return to the same place they were born to spawn. Other fish, such as sardines, move from cool to warmer waters along the coast of South Africa between May and July. The Monarch butterfly migrates from the Rocky Mountains in the USA to overwinter in Mexico, which is considerably warmer.

- **Atmospheric gases**

The distribution of organisms is also affected by the gases that are present. Many of these are produced by human activity, often as a result of transport or industry. Vehicles or machinery powered by fossil fuels release oxides of carbon, sulfur and nitrogen. Lichens are particularly sensitive to air pollution and will only grow large or in high numbers in clear air. In this way they are an indicator of clean air. They are another example of bioindicator species (Table 19.2). Lichens are fascinating organisms made up of a species of alga and a second species of fungus. These two separate organisms grow together in a mutualistic relationship, in which both benefit. Some lichens are thought to be among the oldest living things on Earth.

<table>
<thead>
<tr>
<th>Type of lichen</th>
<th>(1) Common orange lichen, quite tolerant of moderate pollution levels</th>
<th>(2) Quite a common lichen, but dies quickly if pollution levels rise</th>
<th>(3) A common woodland lichen and an indicator of clean air</th>
<th>(4) Beard lichen, only survives in pure air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum level of sulfur dioxide tolerated</td>
<td>70µg/m³</td>
<td>60µg/m³</td>
<td>50µg/m³</td>
<td>35µg/m³</td>
</tr>
</tbody>
</table>

**Table 19.2** Common lichens that act as bioindicators of air pollution from sulfur dioxide.
Chapter review questions

1. Define the term ‘sampling’.
2. Name the square frames using in sampling.
3. Explain why we do not sample animals using quadrats.
4. Name the three main processes in the carbon cycle.
5. Name the main processes in the water cycle.
6. Define the term ‘decomposition’.
7. Describe how cacti are adapted to live in the desert.
8. Describe how camels are adapted to survive without daily access to water in the desert.
9. Define the term ‘global warming’.
10. Describe some effects of global warming.

11. What are the two factors that make an ecosystem?
12. Explain why we do not simply throw quadrats and sample where they land.
13. Give the usual dimensions of quadrats.
14. Define the term ‘ecology’.
15. Define the term ‘systematic sampling’.
16. Describe how systematic sampling using a quadrat is different from random sampling. Explain why you would use systematic sampling.
17. Name the line along which a quadrat is placed during systematic sampling.
18. Describe the conversion of carbon in photosynthesis.
19. Describe the conversion of carbon in respiration.
20. Describe the conversion of carbon in combustion.
21. Describe what happens to the carbon in dead plants and animals.
22. Explain why decomposition is an essential process.
23. Describe the factors that increase the rate of decay.
24. Explain why Tollund Man was discovered so well preserved in a peat bog.
25. Define the term ‘bioindicator’.
26. Explain how the greenhouse effect is causing global warming.

27. Describe what three factors (not species) you might measure inside a quadrat.
28. Suggest why, on a rocky seashore, you might want to sample systematically rather than randomly.
29. Define the term ‘infiltration’.
30. Define the term ‘subsurface flow’.
31. Name the underground ‘reservoirs’ of water found in places such as the Peak District and South Wales.
32. Explain why animals migrate.
33. Describe how lichens are a bioindicator for pollution.
34. Describe how you would expect lichens to look if you completed an ecological investigation into their growth in areas with polluted air and areas with clean air.
19 Organisation of an ecosystem

Practice questions

1 Figure 19.18 below shows the carbon cycle.

**Table 19.3**

<table>
<thead>
<tr>
<th>Month</th>
<th>Mass of leaf litter in g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pine forest</td>
</tr>
<tr>
<td>0</td>
<td>500</td>
</tr>
<tr>
<td>1</td>
<td>430</td>
</tr>
<tr>
<td>2</td>
<td>421</td>
</tr>
<tr>
<td>3</td>
<td>401</td>
</tr>
<tr>
<td>4</td>
<td>382</td>
</tr>
<tr>
<td>5</td>
<td>387</td>
</tr>
<tr>
<td>6</td>
<td>362</td>
</tr>
</tbody>
</table>

a) i) The leaf litter from which woodland decayed more? [1 mark]

ii) How much mass was lost as it decayed? [1 mark]

iii) In the table there is an anomalous result. What does this mean? [1 mark]

b) Suggest why both leaf litters lost most mass within the first month. [1 mark]

c) Name two organisms that can bring about decay. [2 marks]

2 Some farmers are starting to leave unploughed strips of land along one side of their fields, as these are important to wildlife. They provide an important habitat and refuge for many species and allow movement from field to field. A student wanted to find out whether leaving strips of land in a field increases plant biodiversity. Before starting he suggested to his teacher that he should place the quadrat in areas he considered to have the most plants.

a) Explain why this would be wrong. [2 marks]

b) Describe how you would investigate whether leaving a strip of land in a field increased plant biodiversity. [4 marks]

3 Nadine carried out an experiment to examine decay in leaf litter in two woodland habitats: a pine forest (coniferous) and an oak woodland (broadleaf). She removed 500 g of leaf litter from three forest floors and placed it into black bin bags. She then recorded the starting mass of each bag and sealed the bags and left each of them in a separate bin. The bins were sealed but not air tight; however, water could not get in. Nadine re-weighed the bags every month for 6 months.

The results of the experiment are shown in Table 19.3.

a) i) In which form does carbon exist in the atmosphere? [1 mark]

ii) Line A represents respiration; give two other lines that also represent this. [2 marks]

b) Line L represents combustion of fuels. In 1998 5.4 billion tonnes of carbon was released into the atmosphere. In 2014 it was 9.9 billion tonnes of carbon. Calculate the percentage increase in the amount of carbon released. Show your working. [2 marks]

c) An increase in levels of carbon dioxide in the atmosphere is thought to lead to which process? [1 mark]

2 If you wanted to estimate the population of a plant species in a field which of the following methods would you use? [1 mark]

A Mark and recapture
B Systematic sampling using a transect
C Random sampling using quadrats
D Field notes

3 Nadine carried out an experiment to examine decay in leaf litter in two woodland habitats: a pine forest (coniferous) and an oak woodland (broadleaf). She removed 500 g of leaf litter from three forest floors and placed it into black bin bags. She then recorded the starting mass of each bag and sealed the bags and left each of them in a separate bin. The bins were sealed but not air tight; however, water could not get in. Nadine re-weighed the bags every month for 6 months.

The results of the experiment are shown in Table 19.3.

4 Some farmers are starting to leave unploughed strips of land along one side of their fields, as these are important to wildlife. They provide an important habitat and refuge for many species and allow movement from field to field. A student wanted to find out whether leaving strips of land in a field increases plant biodiversity. Before starting he suggested to his teacher that he should place the quadrat in areas he considered to have the most plants.

a) Explain why this would be wrong. [2 marks]

b) Describe how you would investigate whether leaving a strip of land in a field increased plant biodiversity. [4 marks]

5 A teacher asked their class of 10 students to find out how many daisies were in the 100 m² school field. One student suggested that the class go outside and together count all of the daisies on the field by splitting the field into 10 zones. The teacher said that this method would take too long and estimation using random sampling could be used instead.

Describe how a method using random sampling could be used to produce an estimation in a shorter period of time. [6 marks]
Sampling and bias
Ecology is often referred to as the ‘study of distribution and abundance’. Putting it simply, this means how many of a particular type of organism are in an area and where they are found.

Because of the complexity of environments and habitats it is almost impossible to measure the distribution and abundance of organisms in a particular area, as it would take too long and cost too much to do. Instead, ecologists need to make an estimate by sampling. They will want their estimate to be the best estimate that it can be. This means that their results need to be accurate and precise.

Questions
1 Define the terms ‘accurate’ and ‘precise’.
2 How can ecologists ensure that their results are precise?

Ecologists also need to ensure there is no bias in their results. Bias is when evidence is shifted in one direction. Bias can occur because a person wants something to be proven and their presentation of material reflects this, or it can be due to errors in estimating values or collecting data.

Questions
3 Why might a pharmaceutical company be biased in reporting data on the effectiveness of a new drug?

Ensuring that the method used to collect data truly reflects what is occurring can reduce measurement bias. To do this, measurements need to be taken accurately and the experiment needs to be a fair test with controls kept constant.

Sampling bias is introduced when the sample used is not representative or is inappropriate for the aim of the investigation. For example, if an ecologist was studying limpets (a type of marine mollusc) along a rocky shore and they only examined two quadrats – one on some dry rocks and one in a sandy area – then their estimate for abundance would be much lower than the true abundance.

To reduce the impact of sampling bias, ecologists must ensure their sample is big enough to calculate a best estimate for their mean. They also must ensure their samples are random. A random sample is one in which every potential sample plot within a studied area has an equal chance of being chosen. To carry out random sampling usually a random number table (found in statistical book) or a random number generator is used.

Figure 19.22 shows a section of rocky shore with the distribution of the three species that live there. The picture is 15 × 15 cm long and is split into 36 equally sized quadrats. Using dice, you are going to select random quadrats to sample. To do this, roll two dice. The numbers that come up
show you the coordinates to pick. If you rolled a 5 and a 1 you would count five across and one up. Repeat this process six times to pick six random samples. Count the number of each species present and record your results in a table like Table 19.3.

Table 19.3

<table>
<thead>
<tr>
<th>Coordinates for the quadrat</th>
<th>Number of limpets</th>
<th>Number of barnacles</th>
<th>Number of dog whelks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ( , )</td>
<td>![Limpet Image]</td>
<td>![Barnacle Image]</td>
<td>![Dog Whelk Image]</td>
</tr>
<tr>
<td>2 ( , )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 ( , )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 ( , )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 ( , )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 ( , )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Questions**

4 Which species showed the highest abundance?

5 Compare your estimation for abundance for the number of dog whelks with the actual abundance (count all of them). Do you think your sample size was large enough to not be biased?

6 A dog whelk is a predator. Explain why its abundance is lower than that of the barnacles.
For much of our early existence humans lived as hunter-gatherers. We moved from place to place looking for food, shelter and water. We didn’t damage our environment because we needed it to survive. We lived in balance with the other species around us. In recent years human activities, especially those that release pollution, have caused tremendous and often irreversible damage to our environment. Will we ever return to living more naturally? Or will we pollute our planet beyond repair before we learn to?

This chapter covers specification points 4.7.3.1 to 4.7.3.6 and is called Biodiversity and the effect of human interaction on ecosystems. It covers biodiversity, waste management, land use, deforestation, global warming, and maintaining diversity.
Biodiversity is a measure of how many different species of organism live in the same geographical area. All species of life are included in biodiversity, including animals, plants, fungi and microorganisms.

Biodiversity is not the same all over the world. Areas with high biodiversity include tropical rainforests and ancient oak woodlands. We find a huge number of different species of plant, animal and microorganism. So we describe these as very biodiverse areas. Areas with low biodiversity include deserts and the polar regions. Fewer species are found. Sadly some areas of high biodiversity, such as the rainforest, are being destroyed by human activities, including deforestation for farming. These can reduce biodiversity significantly. Sadly, it is only relatively recently that humans have taken some measures to stop this.

High biodiversity ensures the stability of an ecosystem. It reduces the dependency of species on each other for food, shelter and the maintenance of the environment.

Biodiversity is often highest in the tropical regions. It is in these regions that tropical rainforests are found. A good example of this is the island of Borneo in South East Asia. It is the third largest island in the world and is one of the most biodiverse places on Earth. It has just under 20 million people, but over 15 000 species of plants and nearly 1500 species of amphibians, birds, fish, mammals, reptiles and insects. Borneo is so biodiverse because it is made up of many different types of habitat. The different types of forests include tropical rainforests, mangrove trees (near the coast), peat-swamp forests and high forests on Mount Kinabalu. In each of these different habitats different species have evolved to live. New species are continually being found in Borneo and many of these are found there and nowhere else. Recently scientists have found a lungless frog, which can glide from tree to tree!
Waste management

The total population of humans on Earth is increasing at a staggering rate. One hundred years ago there were fewer than two billion people and 200 years ago it was approximately one billion. Estimations show that the population might rise to 16 billion by the end of this century. Where will these people live, what will they eat and where will their fresh water come from? Other estimates put the population as low as six billion by 2100. This reduction might come from famine on a grand scale or a new pathogen spreading a disease. The last time the population didn’t increase continually was at the end of the Great Famine and Black Death in 1350.

A British scholar called Reverend Thomas Malthus (1766–1834) wrote a book called *An Essay on the Principle of Population* in which he incorrectly predicted that the continued growth of our population would use up all food supplies by the mid-19th century. This clearly has not happened all over the world, but it has in some parts. Our developing use of farming machinery, fertilisers and pesticides has meant that many parts of the world have not suffered food shortages. But each year we hear of new famines or droughts in some areas.

Food shortages are not the only consequence of an increasing population. More people means communicable diseases could increase. Other consequences include pollution, deforestation and global warming. These kill plants and animals, which can reduce biodiversity.

Water pollution

Water is vital for all known forms of life. Over half of your body is made from water. The European Food Agency recommends that men drink 2 litres and women drink 1.6 litres of water per day. As well as for drinking directly ourselves, we use water for growing our food, washing, transportation (up and down rivers and canals and across lakes and oceans), and for finding food. As a consequence, water pollution is a serious challenge facing the world today and often results in loss of life or poor health. It is estimated that approximately 500 people still die in India each day because of polluted water. Approximately 1.2 billion people worldwide do not have access to clean water.

Water can be polluted by pathogens that cause communicable diseases. These include species of *Salmonella* bacteria, the *Norovirus* and parasitic worms. These are often found in water as a result of contamination from sewage. Urban areas of developed countries have sewage treatment centres to which sewage travels in underground sewers. This poses little threat to drinking water. In many other parts of the world, sewage is not transported away by underground sewers. Open sewers travel through parts of many cities in the developing world. These can run straight into streams and rivers and then concentrate in lakes or by the sea.
20 Biodiversity and the effect of human interaction on ecosystems

Chemical pollution

Other contaminants include organic chemicals: pesticides and waste from factories and industry. In 1956 a condition named Minamata disease was first discovered. This is named after a nearby city in Japan. From 1932 to 1968 a chemical company called Chisso pumped waste into the local bay. This included dangerously high levels of mercury, a toxic metal. This was found in small quantities in zooplankton at the bottom of the food web. Because it cannot be excreted once consumed, mercury bioaccumulates. This means that it is found in much higher concentrations in higher trophic levels. This included fish and the local inhabitants that ate them. Over 2500 people have been diagnosed as having Minamata disease, with neurological issues including damage to vision, hearing and speech.

Some farmers overuse fertilisers, which then wash off fields and concentrate in slow-moving water such as ponds and lakes. Here the fertiliser can speed up the growth of algae, which can form a ‘bloom’. This can cover an entire lake in a few days. At this point the plants below the bloom do not receive enough light for photosynthesis. They die shortly afterwards and quickly begin to rot. Microorganisms then feed on the dead organisms, and their respiration uses up much of the oxygen in the lake. Without oxygen, animal life, including fish and invertebrates such as insects, begin to die. In a reasonably short period of time a freshwater lake with many different species existing in a stable ecosystem can be completely destroyed. This process is called eutrophication.

Oil spills

Pollution of our oceans is also occurring on a grand scale. In recent years there have been many oil spills from tankers or the drills from which oil is pumped that have affected natural ecosystems in Alaska, the Gulf of Mexico, France and the Galapagos Islands. The Exxon Valdez oil spill occurred in 1989 in Alaska. This oil tanker spilled between 11 and 38 million barrels of oil over the following few days, causing what is considered to be one of the worst human-made environmental disasters in the world. The remote location of the spill meant that the clean-up was more difficult. It resulted in the deaths of hundreds of thousands of sea birds, thousands of sea otters, and hundreds of seals and bald eagles.

A recent oil spill at an oil rig called Deepwater Horizon occurred in spring 2010 in the Gulf of Mexico. It resulted from a leak of the well on the ocean floor. The US Government estimates that 4.9 million barrels of oil were lost. Much of this oil washed up on the shores of Mexico and the United States. In this area over 8000 different species live. Studies have shown increased concentrations of oil and related chemicals from zooplankton at the bottom of the food web to birds, fish and dolphins at much higher trophic levels. This pollution caused immediate problems, such as lesions on fish, but also longer-terms ones such as mutations in shrimp that meant that in 2012 over 50% were born without eyes or eye sockets.
The build-up of plastic rubbish in our oceans is also a growing concern. Over 8% of all debris in the oceans is plastic. This does not decompose but just breaks into smaller and smaller pieces. These tiny pieces of plastic have been found within plankton and so have entered the food chain. They have even been recorded in the stomachs of sea turtles and albatrosses. Much of this plastic ends up in areas of the ocean, where weaker currents are less likely to disperse it. A large one of these is called the North Pacific Garbage Patch. It is difficult to know exactly how big it is, but estimates range from the size of the state of Texas to twice the size of the whole of the USA.

Test yourself
3 Give the range of estimates for the human population at the end of this century.
4 Name the location of an oil spill.
5 Describe why plastic in the oceans is causing a problem.
6 Describe the effects of mercury poisoning in humans.

Your ecological footprint
Your ecological footprint is a measure of your demand on the Earth’s ecosystems. It gives an area that is needed to support your lifestyle; for example, the area needed to generate your energy, deal with your waste and to build your home. Ecological footprints are measured in hectares. One hectare is 10,000 m², or about the size of a large football pitch. The smaller the footprint, the lower the impact on the environment. What is your footprint?
Pick the answers that best apply to you. Record your totals for each section as you go along. You can have more than one answer in each section.

Water consumption
<table>
<thead>
<tr>
<th>Question</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you have a bath every day?</td>
<td>14</td>
</tr>
<tr>
<td>Do you have a bath once or twice a week?</td>
<td>2</td>
</tr>
<tr>
<td>Do you shower every day?</td>
<td>4</td>
</tr>
<tr>
<td>Do you shower only once or twice a week?</td>
<td>1</td>
</tr>
<tr>
<td>In the summer do you water your garden/wash the car with a hosepipe?</td>
<td>4</td>
</tr>
<tr>
<td>Do you use a dishwasher every day or every other day?</td>
<td>6</td>
</tr>
</tbody>
</table>

Food preference
<table>
<thead>
<tr>
<th>Question</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you and your family tend to buy locally produced fresh products (e.g. bread, vegetables, meat)?</td>
<td>2</td>
</tr>
<tr>
<td>Do you buy more heavily packaged and processed items that are not produced locally?</td>
<td>15</td>
</tr>
<tr>
<td>Do you buy more heavily packaged and processed items but try to get ones produced closer to home?</td>
<td>5</td>
</tr>
<tr>
<td>Do you eat meat once a day?</td>
<td>85</td>
</tr>
<tr>
<td>Do you eat meat once or twice a week?</td>
<td>55</td>
</tr>
<tr>
<td>Do you mostly eat vegetarian dishes?</td>
<td>30</td>
</tr>
</tbody>
</table>

Holiday travel last year
<table>
<thead>
<tr>
<th>Question</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did you fly to Australia or beyond (12+ hours)?</td>
<td>155</td>
</tr>
<tr>
<td>Did you fly to Asia or the Americas (5–12 hours)?</td>
<td>85</td>
</tr>
<tr>
<td>Did you fly to Europe (0–5 hours)?</td>
<td>20</td>
</tr>
<tr>
<td>Did you go by rail or road to Europe (including parts of Britain)?</td>
<td>10</td>
</tr>
<tr>
<td>Did you stay at home?</td>
<td>10</td>
</tr>
</tbody>
</table>

Daily travel
<table>
<thead>
<tr>
<th>Question</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you travel to school in a modern small-engine car?</td>
<td>40</td>
</tr>
<tr>
<td>Do you travel to school in a large car, e.g. a 4X4?</td>
<td>75</td>
</tr>
<tr>
<td>Do you travel to school in a car that is somewhere between a small-engine car and a large car?</td>
<td>50</td>
</tr>
<tr>
<td>Do you travel to school on public transport or on a school bus?</td>
<td>25</td>
</tr>
<tr>
<td>Do you cycle/walk to school?</td>
<td>3</td>
</tr>
</tbody>
</table>

Where you live
<table>
<thead>
<tr>
<th>Question</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you live in a small flat?</td>
<td>7</td>
</tr>
<tr>
<td>Do you live in a terraced house?</td>
<td>15</td>
</tr>
<tr>
<td>Do you live in a large spacious flat?</td>
<td>12</td>
</tr>
<tr>
<td>Do you live in a semi-detached house?</td>
<td>23</td>
</tr>
<tr>
<td>Do you live in a detached house?</td>
<td>33</td>
</tr>
<tr>
<td>Divide the score for where you live by the number of people living in your home, and round this figure up to the nearest whole number.</td>
<td></td>
</tr>
</tbody>
</table>

▲ Figure 20.5 Waste plastic builds up on beaches.
Electricity use

<table>
<thead>
<tr>
<th>Activity</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generating your electricity releases carbon dioxide, so start this section with a score of 75.</td>
<td>75</td>
</tr>
<tr>
<td>Do you always switch off the lights if a room is no longer in use?</td>
<td>–10</td>
</tr>
<tr>
<td>Do you always make sure electrical devices are turned off properly and not left on standby?</td>
<td>–10</td>
</tr>
</tbody>
</table>

Heating your home

<table>
<thead>
<tr>
<th>Activity</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>The heat that keeps you warm probably comes from burning fossil fuel, which releases carbon dioxide. To soak up this greenhouse gas, a wood will have to be planted, using up precious land. So, start this section with a score of 45.</td>
<td>45</td>
</tr>
<tr>
<td>Do you set the thermostat down low, preferring to add another layer of clothing before turning it up?</td>
<td>–5</td>
</tr>
<tr>
<td>Is your home well insulated?</td>
<td>–15</td>
</tr>
<tr>
<td>Is your home is double glazed?</td>
<td>–5</td>
</tr>
<tr>
<td>Do you only turn on the heating when needed, rather than keep it on all year round?</td>
<td>–10</td>
</tr>
</tbody>
</table>

Waste

<table>
<thead>
<tr>
<th>Activity</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>To dispose of waste, you’re once again going to use up valuable land. So, start this section with a score of 100.</td>
<td>100</td>
</tr>
<tr>
<td>Do you have a recycling system in your area and use this to recycle glass, cardboard, paper and some plastic?</td>
<td>–25</td>
</tr>
<tr>
<td>Do you compost organic waste left over from the kitchen and garden?</td>
<td>–5</td>
</tr>
<tr>
<td>Do you avoid generating waste by buying less or reusing things?</td>
<td>–15</td>
</tr>
</tbody>
</table>

Add up your scores for each section to give you a total. Many of the services you use every day, from roads to shops to buildings, make their own demands on land. People who consume more tend to rely more on these services. So, to take account of this, double your score. What does your score mean?

Each ‘point’ in your score is equal to one-hundredth of a hectare. So, for example, a score of 350 is equal to about 3.5 hectares. The average footprint for everyone on the planet should be 1.7 hectares. How do you compare to the average? Compare your score to the other countries shown in the table below. Which country is your result most like?

<table>
<thead>
<tr>
<th>Country</th>
<th>Footprint in ha/capita</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>10.3</td>
</tr>
<tr>
<td>Australia</td>
<td>9.0</td>
</tr>
<tr>
<td>Canada</td>
<td>7.7</td>
</tr>
<tr>
<td>New Zealand</td>
<td>7.6</td>
</tr>
<tr>
<td>Iceland</td>
<td>7.4</td>
</tr>
<tr>
<td>Singapore</td>
<td>7.2</td>
</tr>
<tr>
<td>Norway</td>
<td>6.2</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>6.1</td>
</tr>
<tr>
<td>Finland</td>
<td>6.0</td>
</tr>
<tr>
<td>UK</td>
<td>5.3</td>
</tr>
<tr>
<td>Peru</td>
<td>1.6</td>
</tr>
<tr>
<td>Nigeria</td>
<td>1.5</td>
</tr>
<tr>
<td>Philippines</td>
<td>1.5</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1.4</td>
</tr>
<tr>
<td>China</td>
<td>1.2</td>
</tr>
<tr>
<td>Egypt</td>
<td>1.2</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>0.8</td>
</tr>
<tr>
<td>India</td>
<td>0.8</td>
</tr>
<tr>
<td>Pakistan</td>
<td>0.8</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>0.5</td>
</tr>
</tbody>
</table>

What changes could you make to try to have less of an impact on the planet?

Air pollution

Just as water is a key component of life on Earth, so is the air that all non-aquatic animals breathe or absorb. Pollution of the air is therefore another very serious problem. Air pollution is often caused by waste gases from vehicles or factories, but it can also be caused by particles of solids or liquids. These are called particulates and form the smogs that are often seen cloaking large cities in some parts of the world.

Oxides of sulfur are a common air pollutant produced by human activities. They are also released by volcanoes in large volumes. One example, sulfur dioxide, is produced when petrol and other fossil fuels are burnt and so the increase in motor vehicles in recent years has resulted in more of this pollutant being released. Oxides of nitrogen...
are also formed by burning fossil fuels. These have a reddish-brown colour and form hazes around cities. Sulfur dioxide reacts with water vapour and sunlight, to form sulfuric acid. This can lower the pH of water and result in the formation of acid rain. This can destroy whole forests of trees, affecting entire ecosystems. It also often damages stone buildings and statues.

Carbon monoxide is a colourless, poisonous gas without a smell. This makes it difficult to detect. It is again produced in large volumes by vehicles. It can also be produced during incomplete combustion of natural gas in faulty boilers and of other fuels such as coal and wood. Carbon dioxide is produced when fuels are burnt completely. This is a key greenhouse gas and is responsible for global warming.

Chlorofluorocarbons or CFCs are gases that harm our ozone layer. Before we knew they did this, they were found in many aerosol sprays and as coolants in fridges. Now their use is being phased out. Once released they rise into the atmosphere and react with ozone. Ozone naturally shields us from much of the Sun’s ultraviolet (UV) radiation. A large hole in the ozone layer is now found over Antarctica that stretches as far as Australia, South America and South Africa. As a result there is a higher chance of skin cancers in these locations. It is important you know that this example of air pollution is separate from the greenhouse effect and global warming.

**Land pollution**

Traditionally the volume of waste produced by humans was very low. This has increased with the rapid rise in the population of humans, however. In recent years the culture of ‘make do and mend’ has changed and more people buy replacement items before their old ones have even broken. This is common with technological items such as computers and mobile phones. As a result of this we are throwing away more and more, and much of this goes straight into huge landfill sites, where it is buried. These landfill sites attract vermin, including rats, which can spread communicable diseases. As the items themselves break down they can produce a toxic liquid called leachate and release a large volume of methane, which is also a greenhouse gas. It is particularly important that we dispose of some items such as batteries correctly and that they don’t go into landfill. Batteries contain heavy metals and other toxic chemicals, which can easily pollute local soil and water. Many shops now have battery disposal containers near their tills.

These days more waste is being burnt in incinerators. This reduces the need for landfill and so commonly occurs in smaller, more densely populated countries such as Japan. The heat released is often used to generate electricity, which of course is a positive benefit. However, some examples of air pollutants have been found in higher concentrations close to incinerators.

To reduce the need for landfill and incineration it is very important that we all reduce, reuse and recycle as much as we can. These are often called the three R’s. Reducing means simply having less or going without.
Land use is simply the way that we use land. This can be fields for farming crops (arable) or livestock. It can be managed woods to produce timber. Land can also be used for human habitation (urban). Imagine life about 10,000 years ago. This was towards the end of the Stone Age. Small groups of humans (Homo sapiens) roamed around, hunting and gathering. The number of people per unit of land area was very low. The population density was probably around one person per square mile. They lived very sustainable lives and their impact on the environment was very limited. So much so that it is still very difficult to find any archaeological evidence of their existence. Now the population density has increased to about 120 people per square mile. Our lives are less sustainable and the negative impact that we have on the environment has increased.

Show you can...

Explain how fertilisers can cause water pollution.

Test yourself

8 How can we reduce landfill?
9 Name an air pollutant that is released by volcanoes.
10 Describe the effects of acid rain.
11 Describe the consequences of a hole in the ozone layer.

KEY TERMS

Arable Farming of crops for food.
Sustainable Describes an activity that can continue without damaging the environment.
Around the time of the Stone Age, much of the world was covered in forests and little was used for farming. Now more than 10% of the Earth is used for planting crops, about a quarter of it is used for pasture, and only a third is covered in forests and woodland. A relatively small amount, perhaps 1–2%, is occupied by towns and cities (urban). As these values increase less land is available for other animals and plants.

Some human activities are very damaging to land. These include quarrying and mining. One of the largest mines in the world is called Bingham Canyon Mine in Utah in the USA. This is so large that it can be seen from space. It is over 100 years old and the pit is over half a mile deep and 2.5 miles wide. It covers over 1900 acres, which is the size of more than 2500 football pitches.

Some of our cities have also grown over huge areas. Beijing in China is the largest, with a total area of more than 16 000 square kilometres. London is currently about 40th in this list, with an area of 1600 square kilometres. This means that Beijing is the size of 10 Londons!

**Peat bogs**

A bog is an area of wet soil without trees, where many species of moss grow. The water at ground level is acidic and low in nutrients. Despite this, bogs are very important areas of biodiversity, often containing species that are not found anywhere else. They are generally found in areas of high rainfall and cool temperatures. This, combined with the acidity, results in slow plant growth and also slow decomposition. This means that remains found in peat bogs are very well preserved. Because of these conditions peat accumulates. It is made up of partially decayed vegetation.

Peat is often the first step in the formation of fossil fuels. So it is a very valuable source of fuel in certain parts of the world. Even though it is formed more quickly than fossil fuels, it is still not regarded as a sustainable fuel. Because it is made from decaying plants it is a very important sink of carbon. Burning peat as fuel releases this carbon as carbon dioxide, which causes global warming. Peat used to be used regularly by farmers and gardeners to improve the quality of their soil. In recent years, this use has reduced as people have learnt about the destruction that this practice causes to wetlands.

**Test yourself**

12 Give the current human population density on our planet.
13 Give an example of human activity that can be seen from space.
14 Describe the environmental conditions under which peat bogs develop.
15 Describe the impact that hunter-gatherers had on their environment.

**Show you can...**

Explain how we have changed our environment in the UK since the Stone Age.
Deforestation is the clearance of trees from an area that will then be used for other purposes, commonly farming or urban use. Many trees are also felled for their timber. This is used to make items for us to buy, such as furniture, but also to burn for energy. A large number of people in developing countries still collect firewood each day to burn to cook and keep warm. Deforestation by small communities of people who manage areas of land where they live is probably not a major cause for concern. However, in recent years large areas of forests have been cut down by large companies to feed vast herds of cattle or plant huge fields of crops. This now includes crops used to make a type of fuel called biodiesel.

Deforestation applies to rainforests in the tropics, deciduous woodland found in temperate regions and pine forests nearer the Arctic. Deforestation of the rainforests is often more publicised than other regions, perhaps because of the increasing rate at which the rainforests are disappearing. We have now cut down about half of the rainforest that existed only 75 years ago. Some predictions suggest that only 10% will be left in 2030 unless we take drastic action to reduce this.

Trees take in carbon dioxide for photosynthesis. Here it is ‘locked up’ by being temporarily stored as part of the tree’s biomass. This is for the life of the tree, which can often be hundreds of years. So deforestation reduces this sink for carbon, which means more carbon dioxide is present in our atmosphere. Trees are often burnt when cut down, which further releases carbon dioxide into the atmosphere. This increases the greenhouse effect and therefore global warming.

Deforestation massively reduces the number of different living organisms in that area and so reduces biodiversity. It alone has caused a number of known extinctions. We obviously don’t know how many unknown extinctions it has caused. We think that about 80% of the world’s biodiversity could be in our tropical rainforests. We are losing over 100 different species each day as a result of rainforest deforestation. There is no way that these species will ever be seen again. What if a cure for cancer was waiting to be discovered in a plant species in the rainforest that is now already extinct?

The water cycle is also affected by deforestation. Deforestation results in less transpiration by trees, which means that whole areas end up with a drier climate. This means soils with less water and fewer roots, which are then more likely to turn into desert or suffer erosion and landslides.

Test yourself

16 What proportion of the rainforests have we cut down in the last 75 years?
17 What is the expected proportion of biodiversity found in rainforests?
18 Explain why people cut down trees.
19 Describe a negative effect of biodiesel.
Global warming is the gradual increase in the average temperature of the Earth. This includes its land and oceans. The temperature of the Earth has fluctuated over time. We have had ice ages and periods when animals and plants found in the tropics were present in the UK. These changes happened naturally and not as a result of human activity.

For many years scientists have argued about whether the current change in our climate is a result of human activity or just natural causes. In recent years scientists have become certain that global warming is a result of increased emission of greenhouse gases by us.

The effects of global warming are seen the world over. In Arctic regions we are seeing ice melting, causing glaciers to retreat at record rates. The total area of sea ice is reducing, which means it is ever harder for polar bears to hunt. Throughout the world more freak instances of weather are thought to result from global warming. These include heavy rainfall leading to flash floods, as well as heat waves leading to droughts. The melting of sea ice is causing the sea and ocean levels to rise. Many of the world’s major cities are near the coast and will be lost to the sea if this continues. These include Venice, Amsterdam, New York and London.

Species are migrating away from regions they once lived in to those that have temperatures they are more suited to and where they will find their food. If global warming continues those species found in northern Africa will migrate to southern Europe. Then those found in southern Europe will migrate to northern Europe. Currently the climate in the UK is too cold for tropical mosquitos to survive and so malaria is not present. If global warming continues, how long will it be before they can survive here? Such species migration may have hugely damaging effects on ecosystems.

Many scientists are now predicting that global warming is a big threat to our food security. Perhaps positive changes to reduce global warming will happen faster when our food is threatened.

**Global warming**

- **TIP**
  - It is important that you can explain the impact that global warming has on biodiversity. Remember it is the effects of the increase in temperature, not how it is happening (the greenhouse effect).

- **Figure 20.13** These two photographs show how much the Arctic sea ice retreated between 1980 and 2012 as a result of global warming.

- **KEY TERM**
  - **Food security** How safe the supply of our food is.

**Energy wastage**

- **Activity**
  - Mobile phone chargers left plugged in are responsible for wasting more than £60 million of electricity and releasing a quarter of a million tonnes of carbon dioxide every year. Working as a small group, design a survey to find out what energy-wasting habits students in your year group have. Then design a poster to raise awareness of them and the impact they are having on the planet.

**Greenhouse effect**

- If you stand in a greenhouse (or sit in a car with the windows up) on a sunny day you will quickly get very hot. This is because there is no way that the thermal radiation from the Sun can leave the greenhouse (or the car). This is a model for the effect that increased greenhouse
gases (carbon dioxide, methane and water vapour) have in trapping more heat in our atmosphere. The Sun’s radiation initially penetrates our atmosphere and about 50% is absorbed by the Earth’s surface. The rest is reflected back. Before the last few hundred years most of this radiation would have left the atmosphere and only some would have been retained. This low level of the greenhouse effect actually supports life on Earth and is essential for it to continue.

Recent increases in greenhouse gases released by burning fossil fuels and compounded by deforestation have meant that more greenhouse gases are found in our atmosphere. These increases are relatively small. The Keeling Curve of atmospheric carbon dioxide measured in Hawaii shows that it has increased from about 315 to 400 parts per million since 1960. We are able to estimate the concentration of carbon dioxide in the atmosphere by looking at cores drilled into extremely old ice. In the last 800,000 years these results show that the concentration ranged between 180 and 270 parts per million. Our activity has nearly doubled this for the first time in the last billion years.

Currently China is responsible for the greatest greenhouse gas emissions, at 23% of the world’s total. It is followed by the USA on 15% and all of Europe at 11%. The UK as a standalone country is 15th with 1.4%. When viewed by the number of tonnes of carbon dioxide per person these figures change. Recent data shows Qatar is highest, with a staggering 44 tonnes per person. The USA is 12th with 17.2 tonnes per person. The UK is 43rd with 8.9 tonnes per person. China is 56th with 6.2 tonnes per person. That is still a tremendous amount of carbon dioxide!

Show you can...

Explain how an increase in the greenhouse effect leads to global warming

Maintaining biodiversity

Biodiversity is a measure of the number of different species of plants, animals and microorganisms that live in an area. Habitats with particularly high biodiversity include coral reefs and rainforests. These two habitats are threatened by rising ocean temperatures as a result of global warming and by deforestation, respectively.

Fossils have helped us to look at biodiversity since the earliest forms of life on Earth. We have seen at least five major mass extinctions throughout this time. The most recent mass extinction event is happening now as a result of human activity. This is the first time extinctions have happened as a result of the activity of one particular species.

Test yourself

20 Name three fossil fuels.
21 Which country currently releases the most carbon dioxide as a percentage of total emissions?
22 Describe why we are producing more greenhouse gases now than in past centuries.
23 Describe what effect global warming will have on species distribution.
Many zoos carry out breeding programs in which the reproduction of animals is carefully managed to promote the widest gene pool possible. That is, they want the animals they home to be as close as possible genetically to those found in the wild. This stops inbreeding and the genetic disorders that come with it. Horticultural groups have breeding programs for some species of plant as well.

**Conservation efforts**

Conservation is one way in which countries, organisations and charities and individual people are helping to promote biodiversity. The formation of national parks is one way in which governments are doing this. Currently, there is only one male northern white rhino left in the world. It is continuously protected by armed guards to prevent poaching. This despicable trade has reduced this species to near extinction.

National parks and nature reserves are being used to protect many areas of the world. The Great Barrier Reef is the world’s largest coral reef system off the coast of Australia. It can be seen from outer space and is the largest structure on Earth made by living organisms. It was selected as a World Heritage Site in 1981 and a large part of it is protected by a national park. Other famous national parks include Arenal Volcano National Park in the rainforest of Costa Rica, Pantanal National Park in Brazil and the Serengeti National Park in Tanzania.

A hedge or hedgerow is a line of trees or shrubs that have grown together to form a boundary. These separate areas belonging to different people or keep animals in certain places. Hedges were first used to enclose land in the Neolithic Age, about 5000 years ago. Many hedges date from medieval times. Since then they have become home to many species of animals, plants and microorganisms. In fact, we can date a hedge by the number of woody plant species it has in it. You count the number of different species in 30 yards of hedge and multiply this by 110 years. In recent years farmers have been removing hedgerows to make bigger fields, which are easier to tend using machines such as combine harvesters. The removal of these hedgerows has reduced biodiversity.
The reduction in the world’s biodiversity is finally becoming a political issue. In recent years a number of political parties have raised this as an issue they would like to address. In the UK perhaps the most progressive political party in this regard is the Green Party.

Maintaining biodiversity is arguably hardest for developing countries. Here there are real tensions between the needs of local people who in some cases are in direct conflict with endangered animals. It must be very difficult for an African farmer to not trap and kill leopards that are continually killing livestock.

This tension is also seen at a regional and national level. Many years ago, our ancestors cut down many of the trees that made huge forests that covered the UK. Are we now in an ethical position to ask countries in the developing world with a lower standard of living than ours to not do the same? Norway is one country with a forward-thinking view on this. They have set up an initiative called Norway’s International Climate and Forest Initiative, which has donated hundreds of millions of US dollars per year to reduce deforestation in Brazil and the Congo in Africa.

There are also a number of things you can do as an individual to indirectly and directly increase biodiversity. These include:

- not using pesticides and fertilisers in your garden
- leaving areas to become wild (perhaps with a stack of wood for creatures to hide in)
- reduce, reuse and recycle
- using environmentally friendly detergent and washing-up liquid
- growing wild flowers
- putting waste food into compost, not landfill
- buying organic foods.

Conservation debate

Many organisms that are endangered cannot now survive without the help of humans. In order to try to conserve a species, various peoples’ viewpoints need to be considered. As a class, imagine you are at a meeting to decide whether to make an area of forest a reserve to protect the Sumatran tiger (the world’s most endangered tiger). Hold a class debate to decide whether you think this should happen. Some of you should take on the role of people against the reserve, such as local farmers, loggers working in the forest, and people concerned about tigers leaving the areas and harming people. Others should take on the role of people in favour, such as scientists, representatives from a conservation charity, and local hotel managers and business owners who want the reserve to increase tourism.

Ensure that you think about your character’s role in the debate and back your view up with arguments and evidence.

Test yourself

24 Give an example of an area with low biodiversity.
25 Give an example of an area with high biodiversity.
26 Describe why hedgerow removal damages biodiversity.
27 Define the term ‘biodiversity’.
Chapter review questions

1. Suggest some consequences of the increasing population of humans.
2. Describe the short-term consequences of an oil spill.
3. Define the term ‘smog’.
4. Describe the consequences of acid rain.
5. Explain why it is important that fridges and freezers are recycled properly.
6. Explain why the ozone layer is important.
7. Explain why we should recycle batteries and not put them into landfill.
8. What do the three ‘R’s stand for?
9. Give three examples of materials that are commonly recycled.
10. Define the term ‘deforestation’.
11. Explain why deforestation is often considered a bad thing.
12. Define the term ‘biodiversity’.

13. Describe the symptoms of Minamata disease.
14. Describe the long-term consequences of an oil spill.
15. Name the process that might occur if farmers overuse fertilisers.
16. Describe the formation of acid rain.
17. Give an advantage and a disadvantage of using an incinerator over landfill.
18. Define the term ‘sustainable’.
19. Explain why reusing is more sustainable than recycling.
20. Define the term ‘arable farming’.
21. Explain why the rate of decay is low in peat bogs.
22. Define the term ‘sink of carbon’ and give an example of a carbon sink.
23. Describe the effects of global warming.
24. Define the term ‘food security’.
25. Name three common greenhouse gases.
26. Define the term ‘breeding program’.
27. Define the term ‘conservation’.
28. Suggest why national parks are important for biodiversity.
29. Explain why hedgerow removal is a bad thing in terms of ecology.

30. What is the current global estimate for the number of people without clean water?
31. Explain why high levels of mercury were found in humans after the Minamata disaster.
32. Describe what happens if fertiliser gets into a lake.
33. Explain why the early hunter-gatherer lifestyle is more sustainable than our current lifestyle.
34. Why is the preservation of peat bogs so important?
35. Explain why some people still do not believe that global warming is being caused by increased carbon dioxide levels in the atmosphere.
36. Describe how we can estimate the levels of carbon dioxide in the atmosphere over hundreds of thousands of years.
Practice questions

1 Figure 20.18 shows information on how much different groups of organisms are currently under threat of extinction.

![Figure 20.18](image)

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of species assessed</th>
<th>Number of species assessed</th>
<th>Endangered</th>
</tr>
</thead>
<tbody>
<tr>
<td>plants</td>
<td>12151</td>
<td>70%</td>
<td></td>
</tr>
<tr>
<td>freshwater fish</td>
<td>3120</td>
<td>37%</td>
<td></td>
</tr>
<tr>
<td>invertebrates</td>
<td>7615</td>
<td>35%</td>
<td></td>
</tr>
<tr>
<td>amphibians</td>
<td>6285</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>reptiles</td>
<td>1678</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td>mammals</td>
<td>5490</td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td>birds</td>
<td>r/a</td>
<td>12%</td>
<td></td>
</tr>
</tbody>
</table>

Key:
- critically endangered (where known)
- Endangered or vulnerable
- Source: IUCN

a) i) What does the term ‘endangered’ mean? [1 mark]
   ii) Looking at Figure 20.19, which group of animals is most endangered? [1 mark]
   iii) Thirty per cent of amphibians are endangered; calculate from the number assessed how many this is. Show your working. [2 marks]

b) There are fewer than 40 Amur leopards left in the wild in Siberia, and this species is critically endangered.
   i) Suggest two reasons why Amur leopards might be critically endangered. [2 marks]
   ii) There are a number of conservation strategies used in order to help protect the species from further loss, including captive breeding programmes and educating the local population to prevent poaching and habitat destruction. For each of these two strategies give an advantage and disadvantage of its use. [4 marks]

2 Figure 20.19 shows two fields separated by a river.

![Figure 20.19](image)

a) i) The farmer sprays fertilisers on his crops. Explain why he does this. [1 mark]
   ii) Name another chemical the farmer may spray on his crops. [1 mark]

b) The local water company is concerned that there has been an increase in nitrates in the water supply. The farmer was careful to not spray the area of the field near the river and only sprayed on days with no wind. Suggest how the nitrates could have got in the water. [2 marks]

c) Over time the number of fish in the river has declined and in the summer many are found dead on the banks of the river. Explain how an increase in nitrates in the water could have led to the death of these fish. [4 marks]

3 a) Human activities produce a number of air pollutants. Which of the following gases are produced by the incomplete combustion of fuels? [1 mark]
   A Chlorofluorocarbons (CFCs)
   B Carbon monoxide
   C Methane
   D Nitrogen oxides

b) The global temperature is increasing due to global warming. The increase in greenhouse gases is accelerating this process. Which two gases are known to contribute most to the greenhouse effect? [2 marks]
   A Chlorofluorocarbons (CFCs)
   B Carbon monoxide
   C Carbon dioxide
   D Methane

c) Which of the following is not a consequence of global warming? [1 mark]
   A Glaciers retreating
   B Reduction in sea ice
   C Heavy rainfall leading to flash floods
   D Reduced sea levels

4 Describe the impact deforestation is having on the planet. You should include:
   a) the impact on the environment
   b) the impact on biodiversity. [6 marks]
**Correlation and causation**

A correlation is a relationship between two variables. If one variable changes, so does the other. There are different types of correlation: positive correlations, where the variables increase together, and negative correlations, where as one variable increases the other decreases.

It is often difficult to spot a correlation and whether it is positive or negative simply by looking at data in a table, so scientists draw scatter graphs, or scatter plots. These help them see the trends more clearly, identify any anomalous results and determine the strength of the correlation.

▲ Figure 20.20 Different examples of correlation.
Sometimes you can have a spurious correlation. This is an apparent correlation between two variables when the relationship is not directly between them but from a different variable that affects both of them. For example, the number of churches in a town might show a positive correlation with the number of pubs. This does not mean that because there are more churches more pubs were built, or that because there are more pubs more churches are needed! It is that both are affected by another variable in a similar way – in this case, the population. The bigger the population, the more churches and pubs it supports.

It is important to remember that correlation is not causation. That is, just because two variables show a correlation it does not mean that one thing causes the other. Once scientists find a correlation they must then identify the cause to prove it is not just spurious.

**Question**

1. Look at Figure 20.21. What trend can you see?
2. What type of correlation is this?
3. What could be causing the increased carbon dioxide levels between Figures 20.21 and 20.22?
4. Why do scientists believe that increasing carbon dioxide can cause an increase in temperature?
5. Why do some people disagree that increasing carbon dioxide levels are causing global warming?
6. There is concern that human population growth is accelerating the rate of species extinction. Plot the data from Table 20.1 as a scatter graph and add a trend line.
7. What is the trend shown in your data?
8. What type of correlation does it show?
9. What are the possible causes for increasing number of humans leading to increasing rates of extinction?

**Table 20.1**

<table>
<thead>
<tr>
<th>Population (millions)</th>
<th>Number of estimated extinctions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>2000</td>
</tr>
<tr>
<td>1900</td>
<td>2000</td>
</tr>
<tr>
<td>1950</td>
<td>2000</td>
</tr>
<tr>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>2100</td>
<td>2000</td>
</tr>
<tr>
<td>2500</td>
<td>2500</td>
</tr>
<tr>
<td>2900</td>
<td>7000</td>
</tr>
<tr>
<td>4000</td>
<td>9000</td>
</tr>
<tr>
<td>6600</td>
<td>30000</td>
</tr>
</tbody>
</table>
Trophic levels in an ecosystem

This chapter covers specific points 4.7.4.1 to 4.7.4.3 and is called Trophic levels in an ecosystem. It covers trophic levels, pyramids of biomass and energy transfer.

Lions eat zebras. Zebras eat grass. This is a pretty short food chain, because it only has three levels. This means that the energy in the grass passes into the zebra and then into the lion. Other food chains are longer. Because the organisms at each stage use about 90% of the energy for their own life processes, only 10% is passed on. This means that food chains rarely have more than six levels. Beyond this the organisms at the top of the food chain won’t get enough energy. Can you think of a food chain that is longer than six?
We know that lions eat zebras, which in turn eat grass. This feeding relationship can be shown as a flow diagram:

Grass → Zebra → Lion

This is an example of a food chain. The arrows show the transfer of energy between each organism. They do not show what eats what in the feeding relationship.

A **trophic level** is any level in a food chain or web. The first trophic level is almost always a photosynthesising producer. Because this organism comes first it is sometimes called the primary producer. In the simple food chain above, the primary producer is grass. The organism that appears next in the food chain is a consumer. Because it is the first consumer in the food chain, it is called the primary consumer. It eats the producer (plant or alga) and is therefore a herbivore.

Food chains have different lengths. The organisms that follow the primary consumer are called the secondary consumer, then the tertiary consumer and perhaps the quaternary consumer. All consumers that eat other consumers are carnivores. Food chains don’t often have more consumers than this. The final organism in the food chain is called the **apex predator**. This could be the secondary, tertiary or quaternary consumer.

**Pyramids of biomass**

The mass of the organisms at each trophic level in a food chain can be shown in a **pyramid of biomass**. Biomass is the mass in kilograms or grams of any living or recently dead organisms. So a tree has biomass, whereas a rock just has mass. Usually scientists only measure the biomass of dead organisms when they have been dried in an oven. This is because the mass of organisms varies enormously depending on the amount of water they contain. For example, the mass of you will increase by one
Pyramids of biomass

kilogram if you drink one litre of water. By only measuring biomass of dried tissue we avoid inaccuracies. This does mean that the biomass of organisms can only be measured when they are dead. Most measurements of biomass are estimates to avoid killing too many organisms.

Think about all the biomass of all the lions in Africa. Do you think that the biomass of all the zebras that they have eaten is more or less than that of the lions? It must always be more. A pyramid of biomass is always a perfect pyramid. This means that there must be a greater mass of grass than mass of zebras, which in turn must be greater than the mass of lions. If the mass of zebras was greater than the mass of grass, they would eat it all.

TIP
It is important that you can draw pyramids of biomass if given appropriate data. You also need to be able to calculate the efficiency of energy transfer between trophic levels and explain how the loss of biomass at each level reduces the number of organisms in the next level.

Looking at rock pools

Students observed a rock pool habitat and counted the number of individual organisms seen and what they were feeding on. Their results are shown in Table 21.1.

Table 21.1

<table>
<thead>
<tr>
<th>Marine organism</th>
<th>Number found</th>
<th>Dry mass of one organism in g</th>
<th>Observations of feeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seaweed: ulva fronds</td>
<td>256</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Seaweed: bladder wrack</td>
<td>158</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Flat periwinkle</td>
<td>46</td>
<td>3</td>
<td>Feeding on seaweed</td>
</tr>
<tr>
<td>Edible crab</td>
<td>2</td>
<td>40</td>
<td>Feeding on, dog whelk and shanny</td>
</tr>
<tr>
<td>Common limpet</td>
<td>44</td>
<td>3</td>
<td>Feeding on seaweed</td>
</tr>
<tr>
<td>Dog whelk</td>
<td>12</td>
<td>5</td>
<td>Feeding on limpet and periwinkle</td>
</tr>
<tr>
<td>Shanny (small fish)</td>
<td>2</td>
<td>20</td>
<td>Feeding on shrimp</td>
</tr>
<tr>
<td>Shrimp</td>
<td>6</td>
<td>5</td>
<td>Feeding on seaweed</td>
</tr>
</tbody>
</table>

1 Use the information in Table 21.1 to produce a food web for this rock pool habitat.
2 Use the information in Table 21.1 to determine the total biomass for each species of marine organism found.
3 Using Table 21.1 and your food web determine the total biomass at each trophic level in the rock pool. Use Table 21.2 to record your answers.

Table 21.2

<table>
<thead>
<tr>
<th>Tropic level</th>
<th>Total biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Producer</td>
<td></td>
</tr>
<tr>
<td>Primary consumer</td>
<td></td>
</tr>
<tr>
<td>Secondary consumer</td>
<td></td>
</tr>
<tr>
<td>Tertiary consumer</td>
<td></td>
</tr>
</tbody>
</table>

4 Using your answers from question 3, on squared or lined paper draw a scaled pyramid of biomass for the rock pool.

Show you can...

Describe why we dry organisms before measuring biomass.

Test yourself

1 Define the term ‘biomass’.
2 Where are producers found in pyramids of biomass?
3 Describe why biomass decreases at higher trophic levels.
Transfer of biomass

Plants and algae are only able to use about 1% of the energy transferred by the Sun. They are often then eaten by primary consumers. These are only able to use 10% of the total energy from the plants and algae. They turn this energy into their body tissue (their biomass). Here we can think of energy and biomass as almost interchangeable. So 10% of the energy in the grass that is eaten by the zebras becomes zebra tissue (or biomass). Where does the rest of the biomass go? Not all of the biomass is absorbed into the organism. Some is lost in the animals’ solid waste (faeces). The biggest loss, however, is through the waste products of respiration: water and carbon dioxide.

A food chain shows the feeding relationship between producer, consumers and the apex predator. This is drawn with arrows between the organisms showing the flow of biomass or energy.

Almost all habitats in the world have more than one food chain. These often interconnect with other food chains for neighbouring organisms into food webs. Using the example before, the African grass is also eaten by antelope. Both zebras and antelope are eaten by hyenas as well as lions. As a consequence, food webs are usually much more complicated than food chains. The arrows still show the flow of energy, not just what eats what.

Show you can...

- Explain why higher levels in pyramids of biomass are always smaller.

Test yourself

4. Name the term given to animals that eat plants.
5. Describe what the arrows in a food chain show.
6. Describe the position of a quaternary consumer in a food chain.
Chapter review questions

1. Define the term ‘producer’ and give an example.
2. Define the term ‘biomass’.
3. Define the term ‘consumer’ and give an example.
4. Describe what pyramids of biomass show.
5. Define the term ‘trophic level’.
6. Name the organisms that are almost always at the bottom of food chains.
7. What is the name given to the organism at the highest trophic level?
8. Describe the difference between food chains and webs.
9. Describe what the arrows in a food chain show.
10. What proportion of biomass is transferred between each trophic level?
11. Describe where the remaining 90% of the biomass goes.

12. What is the proportion of energy transferred from the Sun that photosynthetic organisms can actually use?
13. Define the term ‘omnivore’ and give two examples.
14. Define the term ‘decomposer’ and give two examples.
15. Draw a pyramid of biomass for the food chain: grass, rabbit, fox, fleas.
16. Suggest what would happen to the other organisms in this food chain if the foxes were shot.
17. Suggest what would happen to the other organisms in this food chain if a new predator for rabbits was introduced.
18. Explain why there are always more prey than predators.
19. Explain why food chains are usually short.
20. What are four uses of energy at each trophic level?
21. What proportion of oxygen released into the atmosphere is from algae and not trees?
Practice questions

1. Figure 21.3 shows a marine food chain.

   ![Food Chain Diagram]

   a) i) Give the term used to describe the phytoplankton in the food chain. [1 mark]
   ii) Give the term used to describe the great white shark. [1 mark]

   An estimation of the number of organisms and the biomass of each is shown in Table 21.3.

   Table 21.3
<table>
<thead>
<tr>
<th>Organism</th>
<th>Numbers</th>
<th>Estimation of mass of one organism in g</th>
<th>Total biomass in g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phytoplankton</td>
<td>4500</td>
<td>0.5</td>
<td>2250</td>
</tr>
<tr>
<td>Zooplankton</td>
<td>2000</td>
<td>1.0</td>
<td>2000</td>
</tr>
<tr>
<td>Sardine</td>
<td>5</td>
<td>300.0</td>
<td>1500</td>
</tr>
<tr>
<td>Tuna</td>
<td>2</td>
<td>650.0</td>
<td></td>
</tr>
<tr>
<td>Great white shark</td>
<td>1</td>
<td>950.0</td>
<td></td>
</tr>
</tbody>
</table>

   b) i) Use Table 21.3 to calculate the total biomass of the tuna. [1 mark]
   ii) Draw a pyramid of biomass for this food chain. [3 marks]

   c) It is unlikely that the estimation of the mass or number of plankton is correct. Suggest a reason for this. [1 mark]

   Table 21.4 shows data on the daily food consumed by four different species of bird.

   Table 21.4
<table>
<thead>
<tr>
<th>Bird</th>
<th>Mass of bird in g</th>
<th>Mass of food eaten daily in g</th>
<th>Amount of food eaten daily as a percentage of body mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barn owl</td>
<td>350</td>
<td>120</td>
<td>34</td>
</tr>
<tr>
<td>Barnacle goose</td>
<td>2500</td>
<td>770</td>
<td>31</td>
</tr>
<tr>
<td>Blackbird</td>
<td>91</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>Bullfinch</td>
<td>22</td>
<td>35</td>
<td>159</td>
</tr>
</tbody>
</table>

   d) i) Calculate the mass of food eaten by the blackbird as a percentage of its body mass. [2 marks]
   ii) Describe the trend in the amount of food eaten as a percentage of body mass for the four birds. [1 mark]
   e) Use the data to explain which bird would need to spend longer feeding. [1 mark]

2. a) Using Figure 21.4, what is one of the main foods for the Weddell seal? [1 mark]
   A Leopard seal  
   B Herring  
   C Ross seal  
   D Krill

   b) Using diagram 21.4, which is not a food for the leopard seal? [1 mark]
   A Adelie penguin  
   B Crab eater seal  
   C Emperor penguin  
   D Antarctic petrel

   ![Food Web Diagram]
Energy calculations

Being able to carry out mathematical calculations on data is vital to science. One of the most common calculations you will be asked to do is to determine a mean. This is the average for a set of results. You determine a mean by adding all the results together and then dividing by the number of results you have.

Table 21.5 shows the amount of kilojoules (kJ) of energy consumed by five dairy cows in one day.

Table 21.5 The energy consumed by five cows in one day.

<table>
<thead>
<tr>
<th>Cow</th>
<th>Energy consumed in kJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>72056</td>
</tr>
<tr>
<td>2</td>
<td>71002</td>
</tr>
<tr>
<td>3</td>
<td>72444</td>
</tr>
<tr>
<td>4</td>
<td>73008</td>
</tr>
<tr>
<td>5</td>
<td>71150</td>
</tr>
</tbody>
</table>

Questions

1. Determine the mean for the energy consumed per cow in kJ.
2. For every 100 kJ of energy consumed by a cow, only 5 kJ becomes incorporated into the cow’s body as new tissue; 63 kJ is lost as waste.

a) How much is used in respiration to perform the other life processes?
b) Give an example of what one of the life processes could be.
Another common calculation you will be asked to perform is working out a percentage. Remember a percentage is a fraction out of 100. So 25% is 25 out of 100. There are two methods you can use to work out a given percentage of given data. Either convert your percentage into a decimal by dividing by 100 and then multiply by the number you want to know the percentage of. Or you can divide your given number by 100 and multiply by the percentage you want.

Example

At every stage of a food web energy is lost. Producers only capture around 1% of the energy from the Sun. If 912 500 kJ of energy is transferred to a tree, how much can it gain?

\[
\frac{1}{100} = 0.01
\]

\[
912 500 \times 0.01 = 9125
\]

\[
\left(\frac{912500}{100}\right) \times 1 = 9125
\]

Questions

3 Of the 9125 kJ of energy the tree has, only 10% of this is passed on and becomes part of the primary consumer. How many kJ of energy is this?

4 How much energy is lost?

5 Of the energy that is lost, 20% is lost by the primary consumer moving around to locate food and digest it. How much is this?

6 Marine food chains are more energy efficient than terrestrial (land) food chains. Of the energy captured by phytoplankton, 12% is passed onto zooplankton. If 96 000 kJ of energy is captured by phytoplankton, how much is passed on?

7 Why do you think marine food chains are more energy efficient?

Sometimes with percentages you will be asked to express one quantity as a percentage of another. To put it simply, if you are asked to work out what percentage X is of Y, you divide X by Y then multiply by 100.

8 Suggest why all the light reaching a plant cannot be used.

9 Work out the percentage of energy transfer for each stage of this food chain:

- Producers: 90 000 kJ
- Primary consumer: 6300 kJ
- Secondary consumer: 700 kJ
- Tertiary consumer: 56 kJ

Example

If 98 200 kJ of the Sun’s energy reaches a plant and it captures 11 784 kJ, what percentage is this?

\[
\left(\frac{11 784}{98 200}\right) \times 100 = 12\%
\]
We used to think that the seas were filled with limitless numbers of fish and the skies with unlimited numbers of birds. We used to think that we could cut down as many trees as we wanted without any harm. We used to think that we could harvest from our environment at will. In the past this led to well-known extinctions such as the dodo. But extinctions continue today, with up to 140,000 species becoming extinct each year. Now we know that ecosystems are finely balanced and that small changes can have huge effects. We do need to grow enough food to feed us all, but what cost will this have on other species?
Factors affecting food security

The total population of humans on Earth is increasing. There are now over seven billion people alive on the planet, and this figure is rapidly rising. Compare this with less than two billion people 100 years ago and one billion 200 years ago. This rise in population is putting huge pressures on our natural resources. We are using fossil fuels much faster than they are produced. Cities are expanding and space in many city centres has become a premium. Some of the most expensive house prices in the UK are in the centre of London. More than 1.2 billion people on Earth do not have access to clean water. This is one in every six of us.

Another problem caused by the growing world population is food security. This is having enough food to feed a population. This is something that people take for granted in some parts of the world. Can you imagine going to your local supermarket and there not being any food there? Or taking all your savings and still not being able to afford to buy food to feed your family? These situations do exist for some people today, mainly in the developing world.

During 2007–2008 a rise in global food prices occurred as a result of less land being used for farming and more for biofuels, increased oil prices, climate change and population growth. This resulted in the price of grain, in particular, increasing. Grain is a staple food in many parts of the world and so this had huge effects on some communities. The wide range and extent of these contributory factors makes guarding against a similar future rise more difficult. These price rises hit most hard in parts of Asia and Africa. Riots were seen in Burkina Faso, Cameroon, Senegal, Mauritania, Cote d’Ivoire, Egypt and Morocco because basic foods (staples) could not be bought. Riots were also seen in other parts of the world including Mexico, Bolivia, Bangladesh, Pakistan, Sri Lanka and South Africa. In Bangladesh 10 000 workers rioted, smashing up vehicles, factories and shops. They were angry over low wages and high food prices. Some people believe that 30 million of the total Bangladeshi population of 150 million will soon be hungry.

In 2010 global food prices started to rise again. Similar protests occurred again, mainly in African countries. The charity Oxfam have warned that when food prices rise by 1% another 16 million more people fall below the poverty line.
**Farming techniques**

Farms are areas of land on which agriculture occurs. These can be owned by families, communities or companies. Agriculture can be:

- growing crops for food for humans or livestock
- growing crops for fuel
- raising animals to be killed for food
- raising animals for food products such as milk and eggs.

Poultry farms raise chickens, turkeys and ducks for meat and/or eggs. Pig farms raise pigs for meat. Dairy farms raise cattle for meat or milk.

Farming begins at similar points in history in different parts of the world. We changed from **hunter-gatherers** to more settled farming communities about 12,000 years ago. These settlements began in the Fertile Crescent in and around Iraq. In recent years more family-run farms have been taken over by large businesses. Many people object

---

**KEY TERM**

**Famine** An extreme shortage of food often leading to many deaths.

**TIP**

It is important that you can evaluate the advantages and disadvantages of modern farming techniques, given appropriate information.

---

**Show you can...**

Explain some of the causes of famine.

---

**Test yourself**

1. Define the term ‘food security’.
2. What is the proportion of food that is wasted?
3. Describe how some people have reacted to food shortages.
4. Describe the potential effects of a 1% rise in food prices.

---

**KEY TERM**

**Hunter-gatherer** A member of a nomadic tribe who live without farming but by hunting, fishing and collecting wild food.
to this. In the last hundred years the number of farms in the USA has reduced by two-thirds from over six million to just over two million.

- **Monoculture or crop rotation**

  Farms can operate a **monoculture** system. Monoculture means only growing one crop, as opposed to other farms which might grow a range of crops (arable) and raise livestock. The crops can be cereals like wheat and barley or fruits and vegetables. Monoculture means that the farm can specialise in one product only. This means it can work more efficiently in planting and harvesting. If this continues year after year it is called monocropping. This can very quickly lead to nutrient deficiencies in the soil and a build-up of pests. An alternative to monoculture is crop rotation. Here different crops are planted each year in the same fields. This is less damaging to the soil and provides less encouragement for pests.

- **Intensive farming**

  To feed more of the world's population and to generate more money for the farmers or companies that now own many farms, modern techniques of **intensive farming** are now used by many. These techniques maximise yields.

  Intensive arable farming means that the fields are quickly planted with another crop after the last one has been harvested and are not left fallow to recover for very long. Intensive animal farming means that larger numbers of animals are raised in smaller spaces. This can include battery chickens kept in small cages or other farmyard animals like calves kept in small pens. This limits their movement, which restricts their energy loss. Minimising energy loss maximises the yield. In intensive fish farming, fish are kept in underwater cages. Here they can easily be fed a high protein diet to maximise their growth. Many people now object to this type of farming, which is known as **factory farming**, because of animal welfare issues. This is an example of an ethical issue, which means that some people disagree with it for religious or moral reasons.

  Intensive farming also regularly uses fertilisers, herbicides and pesticides. Fertilisers are used to enrich soils, as often intensive farming is monoculture. Herbicides are widely used to stop weeds from competing with crops for water, nutrients, space and light. Pesticides are chemicals used to kill insects that eat crops, but they also kill beneficial pollinating insects.

  As a part of some intensive farming, antibiotics are given in food to animals to prevent or treat any diseases. Some people think that this is a cause of the rapid development of antibiotic-resistant bacteria.

  Intensive farming often uses machines to sow, treat and harvest crops. Hedgerows are often removed to make the use of machines easier. Giant machines including tractors and combine harvesters are used to collect the crops in giant fields in much shorter times than if done by hand or using horses as in previous times.

  Intensive farming is a range of techniques that provide more yield for farmers. However, there is an ecological cost to this in terms of greatly reduced biodiversity.
Unsustainable agriculture

The World Wide Fund for Nature (WWF) states that unsustainable agricultural presents the greatest immediate threat to species and ecosystems around the world. Farmers use a number of techniques that conservation groups like the WWF do not agree with, including:

- removal of hedgerows and increased field size
- increased use of nitrate fertilisers
- increased use of pesticides
- deep ploughing of soil using heavy farm machinery.

Using the internet, research the above practices and explain both their benefits in helping the farmer increase crop yield and the negative impact they can have on the environment. Can you suggest any environmentally friendly solutions to any of the practices?

Organic farming

Organic farming is often thought of as the opposite to intensive farming. In organic farming only natural fertilisers and pesticides are used. Manure or ground-up bones (bone meal) is spread onto fields to help enrich soils in place of chemical fertilisers. Natural pesticides such as pyrethrin from Chrysanthemum cinerariifolium (a flowering plant) are used.

One of the most famous organic farmers is Charles, Prince of Wales (1948–), who runs a 900-acre farm in Gloucestershire called the Duchy Home Farm. When it converted to organic produce in 1986, Prince Charles was initially criticised by many farmers who disliked his rejection of modern techniques. His choice was later vindicated, and many people believe his efforts have been hugely influential in promoting more sustainable farming methods.

Biological pest control

Organic farmers often use biological pest control rather than pesticide. Use the internet to research what this is and the type of organisms that are used to do it.

Without the increased yield from intensive farming, many organically produced products have higher prices in our shops. This is simply because they have cost more to produce. Many people are now happy to pay more for some organic items because they know that the consequences of organic farming are far less damaging to local biodiversity. It is perhaps a little disappointing that even though we know the benefits of organic farming, still less than 1% of the world’s farmland is organic.

Show you can...

Explain the negative consequences of intensive farming.

Test yourself

5 Name a natural pesticide.
6 Why are machines used in many farms?
7 Describe the difference between organic and conventional farming.
8 Describe a consequence of the overuse of antibiotics in farm animals.
Sustainable fisheries

For many years we thought that we could catch as many fish as we wanted from our oceans without having much of an effect on their populations. Now we think that over 85% of the world’s fisheries have been overfished. A common example is the overfishing of Gadus morhua (cod) in the North Sea. Here trawler boats drag huge nets behind them to catch cod and a large number of other species.

In the 1950s about 1.2 million tonnes of fish were caught from the North Sea each year. By 1960 this increased to over two million and by 1980 this reached a high point of over 3.3 million tonnes. To help put this into context, the mass of a small car is between 1 and 2 tonnes. Since then the mass per year has reduced but not to pre-1950 levels yet.

Many ways of protecting the stocks of fish in the North Sea have been tried. The times at which boats can fish has been reduced and the total number of boats has been limited. The total amount of fish that can be caught by boats has also been reduced. This is called a quota. There is of course conflict between the fishing communities that depend upon this trade for their livelihood and conservation campaigners. Fishing is now occurring using nets with larger size holes. This means that fewer juvenile fish will be caught. This increases the likelihood of the fish reproducing and restoring population levels.

Overfishing is not just restricted to the North Sea. Entire fishing industries have collapsed in Peru, where anchovies have been overfished, in Canada with cod, and again in the UK with sole. In recent years Iceland and New Zealand have been praised for the sustainable management of their fisheries.

Sadly fishing practices affect many other organisms, not just the target fish. Sea turtles, dolphins, rays and a large number of other fish species are killed or injured by trawler nets in the North Sea each year. Small changes to any ecosystem can have huge effects. What will the effects be of our overfishing?

Test yourself

9 Define the term ‘fishing quota’.
10 Name a fish that has low levels in the North Sea.
11 Describe why some people don’t like the introduction of quotas.
12 Describe how some other animals are affected by fishing.

Role of biotechnology

Biotechnology is the use of living organisms to develop and make products. We have done this for thousands of years in agriculture and for medicine. In recent years our understanding of genetics has developed, so biotechnology now includes the use of genetic modification, cloning and diagnostic tests such as those using monoclonal antibodies.
Biotechnological agriculture: mycoprotein

Mycoprotein is a protein that comes from fungi. The main type of this on sale in the UK is called Quorn™. The protein is harvested from the fungus Fusarium venenatum. This is a microscopic fungus and so not at all like the mushrooms we know. This is grown in huge containers rather like the fermenters that beer is produced in. These are often called vats. They are kept at a constant temperature that is optimal for growth, often by a water-cooled jacket surrounding them. Oxygen is supplied so the fungus can grow aerobically. Glucose syrup is added as a source of food for the respiring fungus. To help make the protein, nitrogen is also added in the form of ammonia. Under these conditions the fungus can double in mass every five hours. When fully grown the liquid is removed from the vat which leaves behind a yellow mass of protein. This is harvested and purified before being sold.

Mycoprotein is obviously a good source of protein for vegetarians who want to avoid animal products. It is completely meat-free. A small amount of egg is added to help bind the protein together, so it is not suitable for vegans. Mycoprotein is also a good source of fibre. It is low in fat and contains no cholesterol. A very small number of people are allergic to it; 70 times fewer than those that are allergic to peanuts.

A key advantage of mycoprotein is the small amount of land it takes to produce it. Some scientists think that it takes only 15% of the space needed to generate the same protein from beef and about 75% of the space for the same mass of poultry.

Whilst this is an example of biotechnology, the fungus has not been genetically modified.

Biotechnological medicine: genetically modified insulin

Bacteria were among the first organisms that were genetically modified because of their simple genetic structure. The first example of this was in 1978 when American Herbert Boyer (1936–) inserted the human gene for insulin into the bacterium Escherichia coli. More recently similar bacteria have been modified to produce clotting factors for haemophilia sufferers.

Insulin was discovered by Frederick Banting (1891–1941) and Charles Best (1899–1978) in 1921. From this point onwards it was used to treat diabetics. Initially the only source of it was from animals, commonly pigs. It was purified before being used but some people still had allergic reactions to it. In the early 1960s technology had developed sufficiently that synthetic insulin was produced. In 1978 the first insulin was then produced using genetically modified bacteria. Because this was human insulin grown in a bacterium, the cases of allergic reactions dropped significantly. Additionally, any objections by vegetarians or animal-welfare groups were reduced.

Insulin is a hormone and therefore a protein. This means that there is a gene that is responsible for making insulin during protein synthesis.
This gene was identified and cut out of a human cell using an enzyme. This cell could be from any diploid body cell from anyone who doesn’t have diabetes. The gene is exactly the same in all people that don’t have diabetes.

Plasmids are small, circular sections of DNA than can move between bacteria. They provide some genetic variation. A plasmid was then removed from a bacterial cell. This was cut open using the same enzyme that removed the gene from the human cell.

The plasmid was then allowed to infect the prokaryotic bacterium *E. coli*. The plasmid acted as a vector for the human gene to be introduced into the bacterium. As the bacterium began to grow and divide by binary fission it began to produce human insulin because it contained the plasmid with the human gene. In effect we have highjacked the protein synthesis of the bacterium to produce human insulin. There is no such thing as ‘bacterial insulin’ because bacteria don’t have blood, a pancreas or a liver, and so don’t need to lower their blood sugar. The bacterium produced chemically identical insulin to our own because it was made during protein synthesis following the DNA code in the human gene. The bacteria were then grown in large volumes in vats. Now all insulin for the treatment of diabetes is made in bacteria that have been genetically modified to include the human gene for insulin.

**Show you can...**

*Explain how insulin is produced using genetically modified bacteria.*

**Test yourself**

13 What does the term ‘biotechnology’ mean?
14 Which type of organism does mycoprotein come from?
15 Describe why insulin from genetically modified bacteria is better than that from pigs.
16 Describe what is added to a fermenter producing mycoprotein and why.
Chapter review questions

1 Define the term ‘food security’.
2 Suggest some causes of famine.
3 Define the term ‘factory farming’.
4 Give two examples of animals often kept on factory farms.
5 Define the term ‘ethical issue’.
6 Define the term ‘organic farming’.
7 Name a species of fish that has been overfished in the North Sea.
8 Name the organism that mycoprotein comes from.
9 Describe how mycoprotein is grown.

10 What proportion of food is estimated to be wasted in the UK?
11 Define the term ‘monoculture’.
12 Name the alternative to monoculture.
13 Describe two examples of techniques used in intensive farming.
14 Explain why some farmers keep animals in small cages.
15 Explain why the removal of hedgerows is a bad thing for the environment.
16 Explain why organic food is often more expensive than food that has been produced using intensive farming.
17 Define the term ‘quota’.
18 Define the term ‘overfishing’.
19 Define the term ‘biotechnology’.
20 Describe the dietary advantages of mycoprotein over meat.
21 Describe the ecological advantages of mycoprotein over meat.

22 Suggest why farmers use monoculture.
23 Explain why crop rotation is less damaging to the environment than monoculture.
24 Explain why giving antibiotics to farm animals in their food is not thought to be a good idea.
25 Give an example of a natural fertiliser.
26 Give an example of a natural pesticide.
27 Describe how people have tried to protect the fish stocks of the North Sea.
28 Explain why fishing boats now use nets with larger holes.
29 Describe what is added to a fermenter in which mycoprotein is growing.
   Explain why each component is added.
30 Explain how bacteria have been genetically modified to produce insulin.
31 Suggest some advantages of using insulin from genetically modified bacteria.
32 Explain how genetic modification can help haemophilia sufferers.
Practice questions

1 Figure 22.12 shows the food security risk index for 2013.

a) Explain what the term ‘food security’ means. [1 mark]

b) From Figure 22.12, which two of the following countries are classified as being at extreme risk? [2 marks]
   A Ethiopia
   B Yemen
   C Afghanistan
   D Haiti

c) Suggest two reasons countries have a food security risk. [2 marks]

2 Figure 22.13 shows the estimated spawning stock biomass (SSB) for haddock in the North Sea. SSB is the total biomass of haddock that are old enough and large enough to successfully breed.

a) In which year were there the fewest fish of breeding age? [1 mark]

b) Fishing quotas are set to control the amount of haddock that are fished from the North Sea. The quotas are set by the EU and are based on the previous year’s estimates of SSB. In 2013 the SSB was estimated to be around 257 701 tonnes so the total allowable catch for North Sea haddock in 2014 was set at 32 079 tonnes.

i) Suggest why the spawning stock biomass can only be estimated. [1 mark]

ii) Suggest why fishing quotas may have led to the decline in fish stocks after 2003. [1 mark]

d) Other than fishing quotas, give another regulation used to maintain fish stocks. [1 mark]

ii) Explain how this would help sustain the population of haddock. [2 marks]

3 Beef cattle are often reared on factory farms.

a) Define the term ‘factory farming’. [1 mark]

i) Give two methods used in factory farming and explain how they reduce energy loss. [4 marks]

b) Many people do not agree with the factory farming of cattle. Give two arguments they may have against this practice. [2 marks]

c) Quorn mince can be used as a beef substitute.

i) What is Quorn? [1 mark]

ii) Briefly describe how Quorn is produced. [3 marks]
Investigating intensive farming

Battery cages are still the most energy-efficient way of producing eggs, with battery hens producing between 5 and 10% more eggs a year than barn and free range hens. However, consumers are becoming more aware of animal welfare and there has been a shift in buying habits. In 2014, 43% of eggs purchased were free range. Since 2012 all battery hens have to be kept in enriched cages, which are larger than barren cages and contain perches, litter, a device for the hens to shorten their claws and additional nesting space.

Your task is to complete a full scientific investigation to compare the energy efficiency of battery cage farming compared to free-range methods. As with many scientific investigations, you will have to use models in order to gain results. You will be provided with the equipment shown in Figure 22.16.

Firstly, working in small groups discuss what you could do and how you could use the apparatus to find out how energy efficient battery hen farming is compared to free range. Ensure you discuss what your different variables will be and how you will ensure your investigation is a fair test.
Writing up your investigation
When you have collected your data you need to write up your investigation as a formal report. Use the following writing frame to support you in structuring your work.

- **Aim:** You need to tell your reader what you are trying to find out. What is the purpose of your investigation?

- **Hypothesis and prediction:** What do you think will happen? (What is your idea?) What do you predict will happen in your results?

- **Method/plan:** In your method you need to clearly identify your variables (dependent, independent and control). You need to explain exactly what you did in your investigation so that someone else could reproduce the experiment.

- **Results:** Your raw results need to be recorded in a clear table with correct formatting. You also could present the data as a graph (remember to consider which type is most appropriate).

- **Conclusion:** Explain what you found out from your experiment. Don’t just write what happened: try to explain why you think it happened. Remember to link your conclusion to your aim and your original prediction and hypothesis.

- **Evaluation:** Firstly, evaluate your method: did this allow you to get the result you needed? Were there any issues? How could you improve the method? Secondly, evaluate your data. Was your data accurate? Did you have any anomalies? What could have caused them? Were there any sources of error? Is your data precise, repeatable and reproducible? If not, why not? How could you have changed things to ensure repeatability and reproducibility? Finally, finish by evaluating your conclusion. Did your method and results allow you to draw an appropriate conclusion? Why or why not? Is your model good enough to draw comparisons with real hens?
Glossary

**Abiotic factors** The non-living parts of the environment.

**Acid rain** Precipitation that is acidic as a result of air pollution.

**Accommodation** Changing the shape of the lens in your eye to focus on near or far objects.

**Active site** The region of an enzyme that binds to its substrate.

**Active transport** The net movement of particles from an area of low concentration to an area of higher concentration using energy.

**Adrenal glands** Glands that produce adrenaline.

**Adrenaline** A hormone produced by your adrenal glands that causes an increase in heart rate ready for a ‘fight or flight’ response.

**Aerobic** In the presence of oxygen.

**Anaesthetic** A drug that stops all pain sensation and can be local or general (throughout an organism).

**Antibiotic** A group of medicines, first discovered by Sir Alexander Fleming, that kill bacteria and fungi but not viruses.

**Antibody** A protein produced by lymphocytes that recognises pathogens and helps to clump them together.

**Anti-diuretic hormone (ADH)** A hormone produced in your pituitary gland that regulates the volume of urine you excrete.

**Antigen** A protein on the surface of a pathogen that your antibodies can recognise as foreign.

**Antiseptic** A substance applied to the skin or another surface to destroy pathogens.

**Antitoxin** A protein produced by your body to neutralise harmful toxins produced by pathogens.

**Apex predator** The final organism in a feeding relationship.

**Arable** Farming of crops for food.

**Artery** A large blood vessel that takes blood from the heart.

**Asexual reproduction** Another name for selective breeding.

**Atrium (plural atria)** An upper chamber of the heart surrounded by a thin wall of muscle.

**Auxin** A type of plant hormone responsible for cell elongation.

**Axon** The extension of a nerve cell along which electrical impulses travel.

**Behavioural adaptation** An advantage to an organism as a result of behaviour, such as a courtship display.

**Benign** A non-cancerous tumour that does not spread.

**Biconcave** Describes a shape with a dip that curves inwards on both sides.

**Bile** A green-coloured liquid produced by your liver, stored by your gall bladder and released into your small intestine to help break down fats.

**Binary fission** The asexual reproduction of bacteria.

**Bioaccumulation** The asexual reproduction of bacteria.

**Bioindicator** An organism whose presence or absence tells you about the cleanliness of an ecosystem.

**Biomass** Tissue from living or recently dead organisms.

**Biotechnology** The use of living organisms to develop and make products.

**Biotic factors** The living parts of the environment.

**Blood plasma** The straw-coloured liquid that carries our blood cells and dissolved molecules.

**Breeding program** Activity of zoos to breed captive animals together to increase their gene pool.

**Capillaries** Tiny blood vessels found between arteries and veins that carry blood into tissues and organs.

**Carcinogen** A cancer-causing substance.

**Carnivore** An organism that only eats animals.

**Cause** The act of making something happen.

**Cell elongation** The lengthening of specific cells by plants as a result of hormones.

**Central nervous system (CNS)** The brain and spinal cord.

**Cerebellum** A part of the back of the brain that coordinates muscular activity.

**Cerebral cortex** The outer layer of the brain, which plays an important role in consciousness.

**Chemical bond** The attraction between atoms that holds them together to form molecules.

**Chitin** A polymer made from sugars that forms the cell walls of fungi and the exoskeleton of insects.

**Cholesterol** An important biological molecule for cell membranes but leads to atherosclerosis if found in high levels in the blood.

**Chromatid** A copy of a chromosome during cell division.

**Chromosome** Structure containing DNA, found in the nucleus of eukaryotic cells.

**Clit** Tiny hair-like projections from ciliated cells that waft mucus out of the gas exchange system.

**Clone** An organism produced asexually that has identical genes to its parent.

**Cloning** The asexual reproduction of an organism to produce genetically identical offspring.

**Collagen** The main structural protein in animal connective tissue such as tendons, ligaments and skin.

**Combustion** Burning.

**Common ancestor** An organism from which others have evolved.

**Communicable** A disease that can be transmitted from one organism to another.

**Community** A group of two or more populations of different species that live at the same time in the same geographical area.

**Competition** The contest between organisms for resources such as food and shelter.

**Computer modelling** Using computer software to theoretically examine or test.

**Concentration gradient** A measurement of how a concentration of a substance changes from one place to another.

**Concordant results** Results that are similar.

**Cones** Light-sensitive receptor cells on your retina in the back of your eye that let you see in colour.

**Conservation** Protecting an ecosystem or species of organism from reduced numbers and often extinction.

**Conservation** Protecting an ecosystem or species of organism from reduced numbers and often extinction.
Consumer Any organism in a feeding relationship that eats other organisms for food.

Continuous (data) Data that come in a range and not in groups.

Control variable This is the variable that can affect the outcome of an investigation and therefore must be kept constant or monitored. If all control variables are kept constant then the experiment is a fair test.

Coronary arteries Arteries that supply the heart muscle with oxygenated blood.

Corpus luteum After ovulation the empty follicle turns into this and releases progesterone.

Correlation When an action and outcome are linked but the action does not necessarily cause the outcome.

Creationism A belief that God created all the organisms on Earth.

Cross-pollination When pollen from one plant fertilises ova from a different plant.

Cystic fibrosis (CF) A genetic disorder in which sufferers inherit a recessive allele from both parents and have excess mucus in their lungs.

Cytokinesis The final part of the cell cycle (after mitosis), in which a cell splits into two.

Daughter cells The cells produced during mitosis.

Deciduous Describes broadleaved trees that drop their leaves in winter.

Defecation Removing solid waste from the body.

Deficiency A lack or shortage.

Deforestation Cutting down of trees (often on a large scale).

Denatured A permanent change to an enzyme as a result of extremes of pH and temperature, which stop it working.

Dendrites The branched beginnings of neurones, which can detect neurotransmitters and start another electrical impulse.

Deoxygenated Without oxygen.

Dependent variable This is the variable that is measured or recorded for each change of the independent variable.

Diabetes A non-communicable disease that reduces control of blood glucose concentrations.

Diagnostic test A medical procedure that tells a patient whether they have an infection or condition.

Differentiate To specialise, or adapt for a particular function.

Diffusion The net movement of particles from an area of high concentration to an area of lower concentration.

Diploid Describes a cell or nucleus of a cell that has a paired set of chromosomes.

Discontinuous (data) Data that come in groups and not a range.

DNA (deoxyribonucleic acid) The genetic information found in all living organisms.

DNA fingerprinting The analysis of differences in DNA to identify individuals.

Dominant Will show a characteristic if inherited from one or both parents.

Double blind trial A medical experiment in which the patients and doctors do not know who has been given the drug and who has been given the placebo.

Double helix The characteristic spiral structure of DNA.

Effector A muscle or a gland.

Efficacy How effective a drug is.

Electron A negatively charged, tiny subatomic particle that is found in shells surrounding the nucleus of an atom.

Electron microscope A microscope that uses electron beams in place of light to give higher magnification.

Embryo splitting The separation of cells of an embryo to increase the number of offspring produced.

Embryo transfer Moving fertilised embryos into other animals to increase the number of offspring produced.

Endothermic reaction A reaction that requires energy to be absorbed to work.

Environmental variation Differences in organisms as a result of the environment in which they live.

Enzyme A biological molecule that speeds up a chemical reaction.

Epidermis The outermost layer of cells of a plant.

Ethene A plant hormone that ripens fruit.

Ethical issue An idea some people disagree with for religious or moral reasons.

Evolution The theory first proposed by Charles Darwin that the different species found today formed as a result of the accumulation of small advantages that were passed through generations.

Excretion The removal of substances produced by chemical reactions inside cells from cells or organisms.

Exothermic reaction A reaction that gives out heat energy.

Extreme environment A location in which it is challenging for most organisms to live.

Extremophile An organism that lives in an extreme environment.

Factory farming Rearing livestock using highly intensive methods.

Famine An extreme shortage of food often leading to many deaths.

Fermentation The chemical breakdown of glucose into ethanol and carbon dioxide by respiring microorganisms such as yeasts.

Fermenters (vats) Giant containers with regulated conditions to maximise the growth of microorganisms.

Fishery A place where fish are reared or caught.

Follicle A structure in an ovary in which an ovum matures.

Follicle-stimulating hormone (FSH) A hormone produced by the pituitary gland that causes an ovum to mature in an ovary and the production of oestrogen.

Food security How safe the supply of our food is.

Fossil record All of the fossils that have been discovered so far.

Gametes Sex cells, e.g. sperm, ova and pollen.

Gene A section of a chromosome made from DNA that carries the code to make a protein.

Genetic engineering A scientific technique in which a gene is moved from one species to another.

Genetic modification As genetic engineering.

Genetic variation Inherited differences in organisms.

Genome One copy of all the DNA found in your diploid body cells.

Genotype The genetic make-up of an organism represented by letters.

Genus The second smallest group of classifying organisms.

Gestation The time between fertilisation and birth.

Gibberellins Plant hormones responsible for cell elongation, seed dormancy and germination.

Global warming The effects of an increase in temperature as a result of the greenhouse effect.

Glucagon A hormone produced in the pancreas that raises blood glucose by breaking down glycogen stored in the liver.

Glycogen An insoluble store of glucose in the liver.

Goitre A medical condition in which your thyroid gland in your neck swells.

Greenhouse effect Increased carbon dioxide and other gases trap more of the Sun's solar radiation in the Earth's atmosphere, leading to global warming.

Haemoglobin The molecule in red blood cells that can temporarily bind with oxygen to carry it around your body.

Haemophilia A genetic disorder in which sufferers inherit a recessive allele from both parents and have difficulties forming blood clots.
Haploid Describes a cell or nucleus of a gamete that has an unpaired set of chromosomes (i.e. only half the normal number).

Heart bypass A medical procedure in which a section of less important artery is moved to allow blood to flow around a blockage in a more important one.

Herbivore An organism that only eats plants.

Heterozygous A genotype with one dominant and one recessive allele.

Homeostasis The maintenance of a constant internal environment.

Homoygous dominant A genotype with two dominant alleles.

Homoygous recessive A genotype with two recessive alleles.

Hormone A chemical (produced in a gland in mammals) that moves around an organism to change the function of target cells, tissues or organs.

Humid Describes an atmosphere with high levels of water vapour.

Hunter-gatherer A member of a nomadic tribe who live without farming but by hunting, fishing and collecting wild food.

Hybridoma A monoclonal antibody-producing cell formed from the fusion of a mouse spleen cell and myeloma cell.

Hydrothermal vents Volcanic vents at the bottoms of seas and oceans, where unique species of life have evolved based upon bacteria feeding on chemicals and not photosynthesis.

Hydrotropism A plant's ability to grow roots towards water.

Hyperopia A medical condition called long-sightedness in which people cannot clearly see objects close to them.

Hyphae Branching filaments of a fungus that spread out.

Hypothesis An idea that explains how or why something happens.

Impermeable Through which a substance cannot pass.

Inbreeding Artificial selection using parents from a closely related group, which reduces variation.

Incomplete combustion The burning of fuel without sufficient oxygen, which produces poisonous carbon monoxide.

Independent variable This is the variable that is changed in an experiment or selected by the investigator.

Infectious Describes a pathogen that can easily be transmitted, or an infected person who can pass on the disease.

Infiltration The movement of water into the ground to become ground water.

Inorganic Compounds that do not contain carbon.

Insecticide A chemical that kills insects.

Insoluble Cannot dissolve.

Insulin A hormone produced in your pancreas that lowers blood glucose by converting it to glycogen and storing it in the liver.

Intensive farming Industrial agriculture to maximise yield, often involving the use of machines, chemical fertilisers and pesticides.

Interdependence All the organisms in a community depend upon each other and because of this changes to them or their environment can cause unforeseen damage.

Interphase The active life of a cell during which the cell prepares for mitosis.

Invasive species An organism that is not native and causes negative effects.

In vitro fertilisation (IVF) A medical procedure in which ova are fertilised outside of a woman, then placed into her uterus to develop into a baby.

Ionising radiation UV rays, X-rays and gamma rays that can cause mutations to DNA.

Kidney dialysis A temporary medical treatment for kidney failure patients where blood is removed from their body, filtered and then replaced.

Kingdom The largest group of classifying organisms, e.g. the animal kingdom.

Lesion A part of an organism that has symptoms of disease, such as a wound, ulcer or abscess.

Limiting factor Anything that reduces or stops the rate of a reaction.

Lipids Fats or oils, which are insoluble in water.

Lock and key hypothesis A model that explains the action of enzymes.

Luteinising hormone (LH) A hormone produced by the pituitary gland that stimulates ovulation.

Lymphocyte A type of white blood cell that produces antibodies to help clump pathogens together to make them easier to destroy.

Lysozymes Antibacterial enzymes found in your tears to prevent eye infections.

Malaria A communicable disease, caused by a protist transmitted in mosquitos, which attacks red blood cells.

Malignant A cancerous tumour that can spread to other parts of the body.

Mass extinction A large number of extinctions occurring at the same time (humans are the latest cause of a mass extinction).

Medulla oblongata A part of your brain above the spinal cord that controls your breathing and heart rates.

Meiosis Cell replication that produces four non-identical haploid cells from one diploid cell.

Menopause The point in a woman's life, usually between 45 and 55, when she stops menstruating and therefore cannot become pregnant.

Menstruating Having a period, as a part of the menstrual cycle.

Meristem An area of a plant in which rapid cell division occurs, normally in the tip of a root or shoot.

Metabolism The sum of all the chemical reactions that happen in an organism.

Methicillin-resistant Staphylococcus aureus (MRSA) A bacterium that has evolved resistance to antibiotics.

Migration Annual movement of animals (often birds) over large distances for food, breeding sites or warmer temperatures.

Mineral ions Substances that are essential for healthy plant growth, e.g. nitrates and magnesium.

Mitochondrion A small cell organelle, in which respiration occurs, found in the cytoplasm of eukaryotic cells.

Mitosis Cell replication that produces two identical copies of a diploid cell.

Monoclonal antibodies Identical antibodies produced from the fusion of mouse spleen cells and myeloma cells.

Monoculture Sustained growth of one species of crop.

Motor neurone A neurone that carries an electrical impulse away from the central nervous system to an effector (muscle or gland).

Mutation A permanent change to DNA, which may be advantageous, disadvantageous or have no effect.

Mycoprotein Protein that comes from fungi, such as Quorn.

Myelin sheath The insulating cover along an axon, which speeds up the electrical impulse.

Myeloma A malignant tumour of white blood cells in bone marrow.

Myopia A medical condition called short-sightedness in which people cannot clearly see objects far away.

Negative feedback control A homeostatic mechanism by which the body detects a change and makes an adjustment to return itself to normal.

Nephron The functional unit of the kidney where excess water, ions and urea are removed from the blood.

Net Overall.
Normal distribution Data that are more common around a mean and form a bell-shaped graph.
Nucleotide A DNA base pair together with a sugar and phosphate molecule that make up the backbone of the double helix.
Oestrogen A female sex hormone produced in the ovaries that controls puberty and prepares the uterus for pregnancy.
Omnivore An organism that eats both plants and animals.
Organelle A part of a cell with a specific function.
Organic farming Non-intensive farming that uses natural fertilisers and pesticides.
Osmosis The net diffusion of water from an area of high concentration of water to an area of lower concentration of water across a partially permeable membrane.
Ova (singular ovum) Eggs.
Overfishing Fishing on a scale so large that the population of species is threatened.
Oxidation Any reaction in which a substance gives up electrons, as when reacting with oxygen.
Oxygen debt The temporary shortage of oxygen in respiring tissues and organs.
Oxyhaemoglobin The name given to the substance formed when haemoglobin in your red blood cells temporarily binds with oxygen.
Palisade mesophyll Tissue found towards the upper surface of leaves with lots of chloroplasts for photosynthesis.
Partially permeable Allowing only substances of a certain size through.
Pathogen A disease-causing microorganism (e.g. a bacterium or fungus).
Peat Partially decayed vegetation.
Pesticides Chemicals used to kill pests.
Phagocyte A type of white blood cell that engulfs pathogens.
Phenotype The physical characteristics of an organism as described by words.
Phloem Living cells that carry sugars made in photosynthesis to all cells of a plant.
Photosynthesis A chemical reaction that occurs in the chloroplasts of plants and algae and stores energy in glucose.
Physiological adaptation An advantage to an organism as a result of a process, such as the production of poisonous venom.
Platuitary gland A gland in your brain that produces growth hormones, ADH, TSH, FSH (in women) and LH (again in women).
Placebo A medicine that has only psychological effects.
Platelets Small structures (not cells) in your blood that fuse together to form a scab.
Population The total number of all the organisms of the same species or the same group of species that live in a particular geographical area.
Positive gravitropism The ability of plant roots to grow downwards.
Positive phototropism The ability of plant stems to grow towards the light.
Precipitation Rain, snow, hail, sleet.
Prediction A statement suggesting what you think will happen.
Producer Any organism that photosynthesises (a plant or alga).
Product The substance or substances produced by an enzyme reaction.
Prokaryotes Prokaryotic organisms (bacteria).
Prokaryotic cells Describes single-celled organisms that do not contain a nucleus.
Progesterone A female sex hormone produced in the ovaries that prepares the uterus for pregnancy.
Punnett square A grid that makes determining the chance of inheriting a characteristic easier to understand.
Pyramid of biomass A graphical way of representing the mass of organisms at each level of a feeding relationship.
Quadrat A square frame used in biological sampling.
Quota A fixed entitlement to catch a specified volume of fish or other yield.
Random errors Errors that vary unpredictably. You can reduce the effect of random errors by taking more measurements and calculating a new mean.
Receptor A cell or group of cells at the beginning of a pathway of neurones that detects a change and generates an electrical impulse.
Recessive Will show a characteristic only if inherited from both parents.
Recycle Changing a waste product into new raw materials to make another.
Reflex arc The route of an electrical impulse that avoids the brain to save time and so helps prevent damage to your body.
Reflex response An automatic response that you do not think about.
Relay neurone A neurone that carries an electrical impulse around the central nervous system (brain and spinal cord).
Repeatable A measurement is repeatable if the same person uses the same method and equipment and gets the same results.
Reproducible A measurement is reproducible if the investigation is repeated by another person or by using different equipment or techniques and the same results are obtained.
Resolution The smallest distance between two separate points.
Respiration The release of energy from glucose.
Ribosome A small cell organelle in the cytoplasm in which proteins are made.
Risk factor Any aspect of your lifestyle or substance in your body that increases the risk of a disease developing.
Rod Light-sensitive receptor cells on your retina in the back of your eye that let you see in low light conditions.
Runoff The movement of water across the surface of land.
Sampling The process of recording a smaller amount of information to make wider conclusions.
Selective breeding A process by which humans have chosen organisms to breed together to develop desirable characteristics, famously in dogs.
Self-pollination When pollen from one plant fertilises ova from the same plant.
Sensory neurone A neurone that carries an electrical impulse from a receptor towards the central nervous system.
Sink A long-term store of a substance, often carbon.
Smog Fog or haze as a result of smoke or other polluting gases.
Soluble Can dissolve.
Speciation The process of forming new species of life.
Species The smallest group of classifying organisms, all of which are able to interbreed to produce fertile offspring.
Sphincter A ring of muscle that can open or close a tube.
Spleen An organ of the immune system, found in the abdomen of most vertebrates, that produces and destroys blood cells.
Spongy mesophyll Tissue found towards the bottom surface of leaves with spaces between the cells to allow gases to diffuse.
Stem cell An undifferentiated cell that can develop into one or more types of specialised cell.
Stent A small medical device made from mesh that keeps arteries open.
Stomata Tiny holes in leaves bordered by guard cells that allow gases to diffuse in and out.
Structural adaptation An advantage to an organism as a result of the way it is formed, like the streamlining seen in fish.
Substrate The molecule or molecules on which an enzyme acts.
Subsurface flow The movement of underground water towards the seas and oceans.
Sustainable Describes an activity that can continue without damaging the environment.
Synapse A gap between the axon of one nerve and the dendrites of another where neurotransmitters transmit the impulse.
Systematic errors Errors that vary by the same amount. They can be caused by the observation methods or instruments. You can reduce the chance of systematic errors by using a different technique or set of equipment.
Testosterone A male sex hormone produced in the testes that controls puberty.
Thyroid gland A gland in your neck that produces thyroxine to regulate how quickly your body uses energy and makes proteins, and how sensitive it is to other hormones.
Thyroid-stimulating hormone (TSH) A hormone produced by your pituitary gland that regulates your thyroid gland.
Transcription The process of making an RNA copy of a gene sequence of DNA.
Transect A line along which systematic sampling occurs.
Transgenic Describes a genetically engineered organism.
Translation The process of making a protein from an RNA copy of a gene sequence of DNA.
Translocation The movements of sugars made in photosynthesis from the leaves of plants.
Transpiration The gradual release of water vapour from leaves to continue the ‘pull’ of water up to them from the soil.
Transplant operation The surgical removal of an organ or tissue from one person and placement of it in another person.
Tropic level A stage in a feeding relationship representing an organism in a food chain or a group of organism in a food web.

True value The value that would be obtained in an ideal measurement.
Turgid Describes swollen cells.
Tubal ligation A contraceptive medical procedure during which a woman’s fallopian tubes are blocked or cut.
Type 1 diabetes A medical condition that usually develops in younger people, preventing the production of insulin.
Type 2 diabetes A medical condition that usually develops in later life, preventing cells from responding to insulin.
Urea A key waste product of protein metabolism in mammals that is excreted in urine.
Vaccine A medicine containing an antigen from a pathogen that triggers a low level immune response so that subsequent infection is dealt with more effectively by the body's own immune system.
Variation The differences that exist within a species or between different species.
Vasectomy A contraceptive medical procedure during which a man's sperm ducts are blocked or cut.
Vasoconstriction The reduction in size of blood vessels to reduce the flow of blood to the surface of the skin and therefore reduce heat loss.
Vasodilation The increase in size of blood vessels to increase the flow of blood to the surface of the skin and therefore increase heat loss.
Vector An animal that spreads a communicable disease.
Vein A large blood vessel that returns blood to the heart.
Ventilation Breathing in (inhaling) and out (exhaling).
Ventricle A lower chamber of the heart surrounded by a thicker wall of muscle.
Villi (singular villus) Tiny finger-like projections that increase the surface area of the small intestine.
Xylem Dead plant cells joined together into long tubes through which water flows during transpiration.
Yield The amount of an agricultural product.
Zooplankton Small or microscopic animals that float in salt water and fresh water and form a part of many aquatic food chains.
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