AQA GCSE

Biology

Third edition

Ann Fullick

Andrea Coates

Editor: Lawrie Ryan

AQA Approved

OXFORD

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We approve textbooks because we know how important it is for teachers and students to have the right resources to support their teaching and learning. However, the publisher is ultimately responsible for the editorial control and quality of this book.

Please note that when teaching the *AQA GCSE Biology* or *AQA GCSE Combined Science: Trilogy* course, you must refer to AQA's specification as your definitive source of information. While this 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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Contents

This book has been written for the *AQA GCSE Biology* and *AQA GCSE Combined Science: Trilogy* courses, making them completely co-teachable. Biology only lessons are easily identifiable with their own black-bordered design, and are also formatted in italics in the below contents list for quick access.

Required Practicals

Practical work is a vital part of biology, helping to support and apply your scientific knowledge, and develop your investigative and practical skills. As part of your GCSE Biology course, there are 10 required practicals you must carry out. Questions in your exams could draw on any of the knowledge and skills you have developed in carrying out these practicals.

A Required practical feature box has been included in this student book for each of your required practicals. Further support is available on Kerboodle.

Required practical		Topic
1	**Using a light microscope.** Use a light microscope to observe, draw, and label a selection of plant and animal cells and include a scale magnification.	B1.2
2	**Investigating the effect of antiseptics or antibiotics on bacterial growth.** Use agar plates and measure the zones of inhibition produced around colonies.	B5.4
3	**Investigate the effect of a range of concentrations of salt or sugar solutions on the mass of plant tissue.** Investigate osmosis by measuring how the mass of plant tissue changes in a range of concentrations of salt or sugar solutions.	B1.8
4	**Use standard food tests to identify food groups.** Detect sugars, starch, and proteins in food using Benedict's test, the iodine test, and Biuret reagent.	B3.3
5	**Investigate the effect of pH on the rate of reaction of amylase enzyme.** Students should use a continuous sampling technique to determine the time taken to completely digest a starch solution at a range of pH values.	B3.6
6	**Investigate the effect of light intensity on the rate of photosynthesis** Use an aquatic plant to observe the effect light intensity has on the rate of photosynthesis.	B8.2
7	**Investigate the effect of a factor on human reaction time.** Plan and carry out an investigation, choosing appropriate ways to measure reaction time and considering the risks and ethics of the investigation.	B10.2
8	**Investigate the effect of light or gravity on the growth of newly germinated seedlings.** Record results both as length measurements and as accurate, labelled biological drawings to show the effects.	B11.9
9	**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.	B16.3
10	**Investigate the effect of temperature on the rate of decay of fresh milk.** Measure the pH change of milk to investigate how temperature affects its rate of decay.	B17.4

How to use this book

Learning objectives

- Learning objectives at the start of each spread tell you the content that you will cover.
- Any outcomes marked with the higher tier icon H are only relevant to those who are sitting the higher tier exams.

This book has been written by subject experts to match the new 2016 specifications. It is packed full of features to help you prepare for your course and achieve the very best you can.

Key words are highlighted in the text. You can look them up in the glossary at the back of the book if you are not sure what they mean.

Many diagrams are as important for your understanding as the text, so make sure you revise them carefully.

Synoptic link

Synoptic links show how the content of a topic links to other parts of the course. This will support you with the synoptic element of your assessment.

There are also links to the Maths skills for biology chapter, so you can develop your maths skills whilst you study.

Study tip

Hints giving you advice on things you need to know and remember, and what to watch out for.

Go further

Go further feature boxes encourage you to think about science you have learnt in a different context and introduce you to science beyond the specification. You do not need to learn any of the content in a Go further box.

Key points

Linking to the Learning objectives, the Key points boxes summarise what you should be able to do at the end of the topic. They can be used to help you with revision.

Practical

Practicals are a great way for you to see science in action for yourself. These boxes may be a simple introduction or reminder, or they may be the basis for a practical in the classroom. They will help your understanding of the course.

Required practical

These practicals have important skills that you will need to be confident with for part of your assessment. Your teacher will give you additional information about tackling these practicals.

Higher

Anything in the Higher Tier spreads and boxes must be learnt by those sitting the higher tier exam. If you will be sitting foundation tier, you will not be assessed on this content.

Using maths

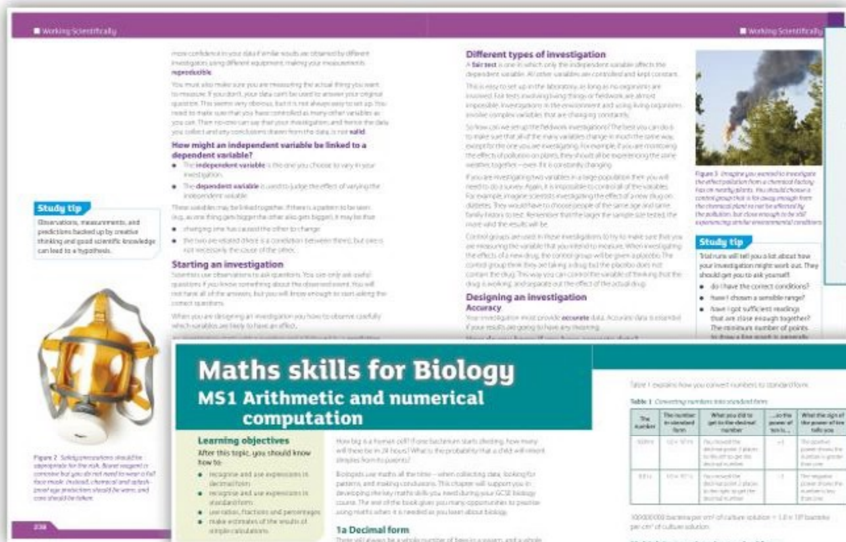
This feature highlights and explains the key maths skills you need. There are also clear step-by-step worked examples.

Summary questions

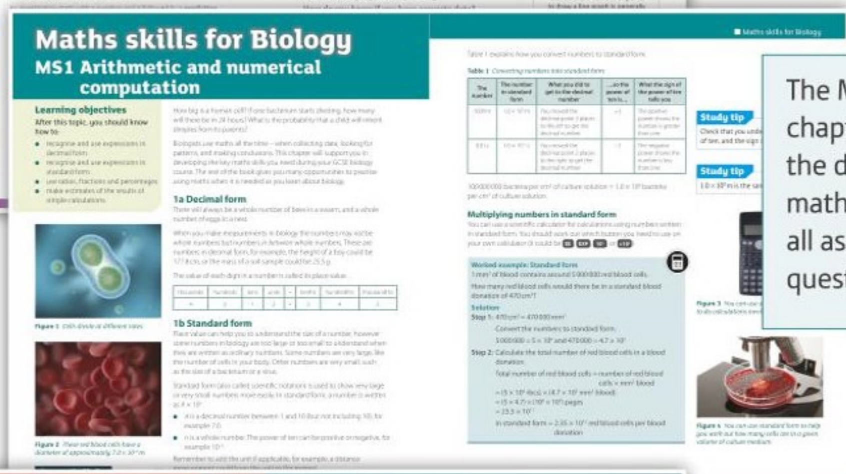
Each topic has summary questions. These questions give you the chance to test whether you have learnt and understood everything in the topic. The questions start off easier and get harder, so that you can stretch yourself.

The Literacy pen shows activities or questions that help you develop literacy skills.

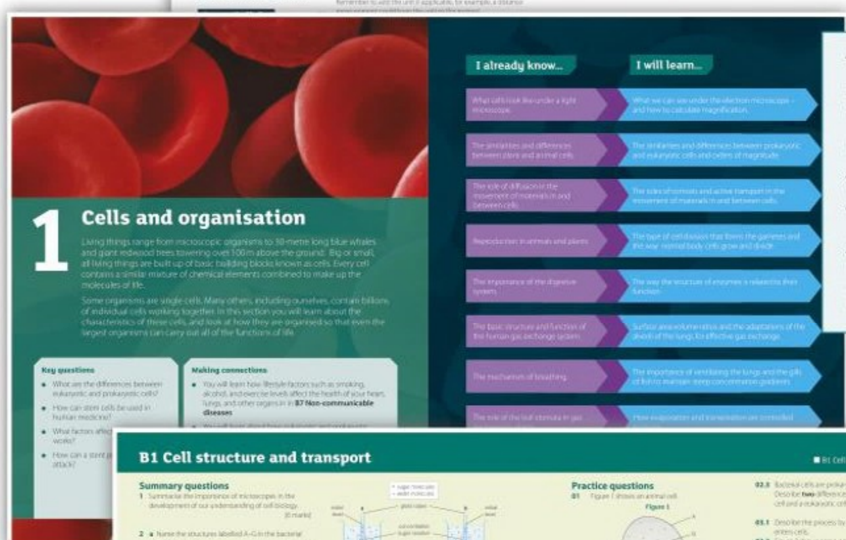
Any questions marked with the higher tier icon H are for students sitting the higher tier exams.



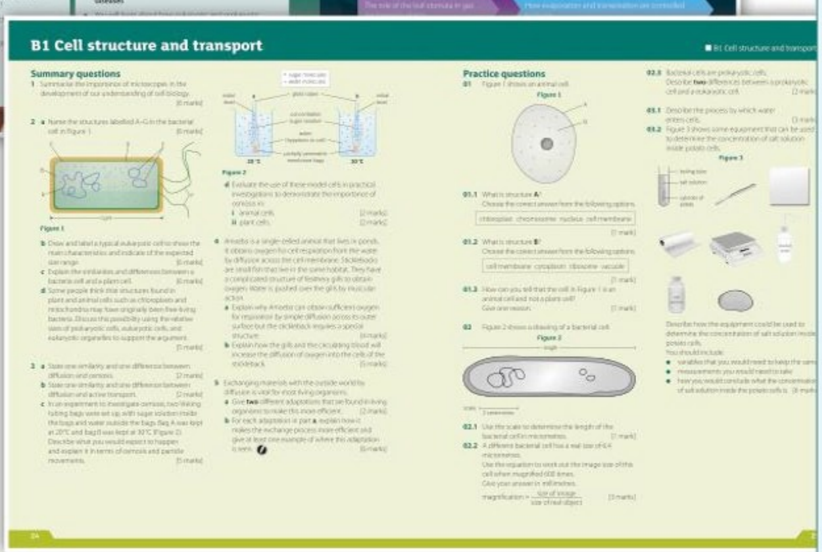
Working scientifically skills are an important part of your course. The working scientifically section describes and supports the development of some of the key skills you will need.



The Maths skills for biology chapter describes and supports the development of the important mathematical skills you will need for all aspects of your course. It also has questions so you can test your skills.



The section openers include an introduction to the section, some key questions the section will answer, and the required practicals in that section. They also introduce the key concepts from KS3 and tell you how they will be developed in that section.



At the end of every chapter there are summary questions and practice questions. The questions test your literacy, maths, and working scientifically skills, as well as your knowledge of the concepts in that chapter. The practice questions can also call on knowledge from any of the previous chapters to help support the synoptic element of your assessment.

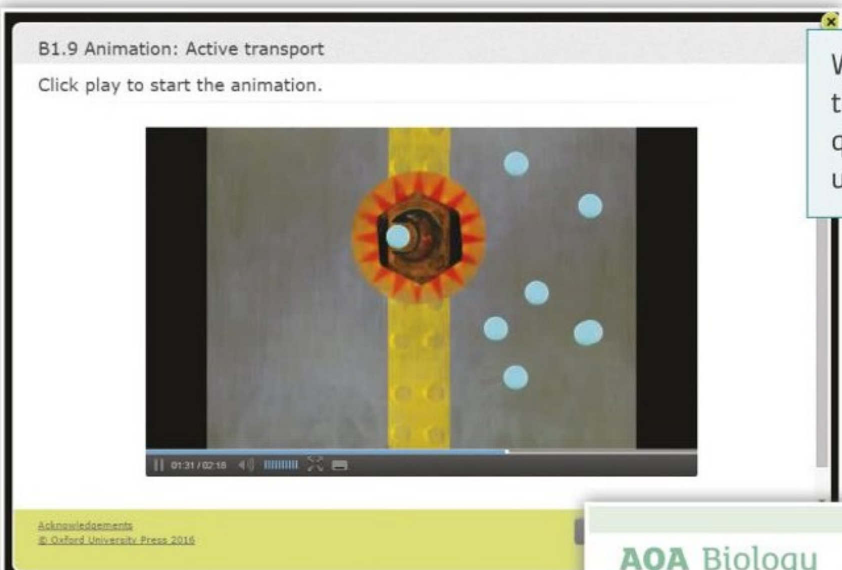
There are also further practice questions at the end of the book to cover all of the content from your course.

Kerboodle

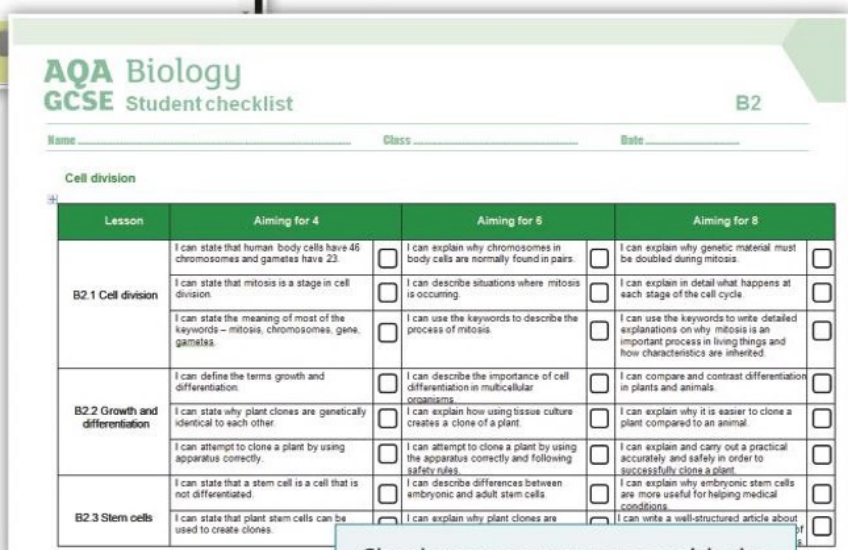
This book is also supported by Kerboodle, offering unrivalled digital support for building your practical, maths and literacy skills.

If your schools subscribes to Kerboodle, you will find a wealth of additional resources to help you with your studies and revision:

- animations, videos, and revision podcasts
- webquests
- maths and literacy skills activities and worksheets
- on your marks activities to help you achieve your best
- practicals and follow-up activities
- interactive quizzes that give question-by-question feedback
- self-assessment checklists



Watch interesting animations on the trickiest topics, and answer questions afterward to check your understanding.



AQA GCSE Biology Student checklist B2

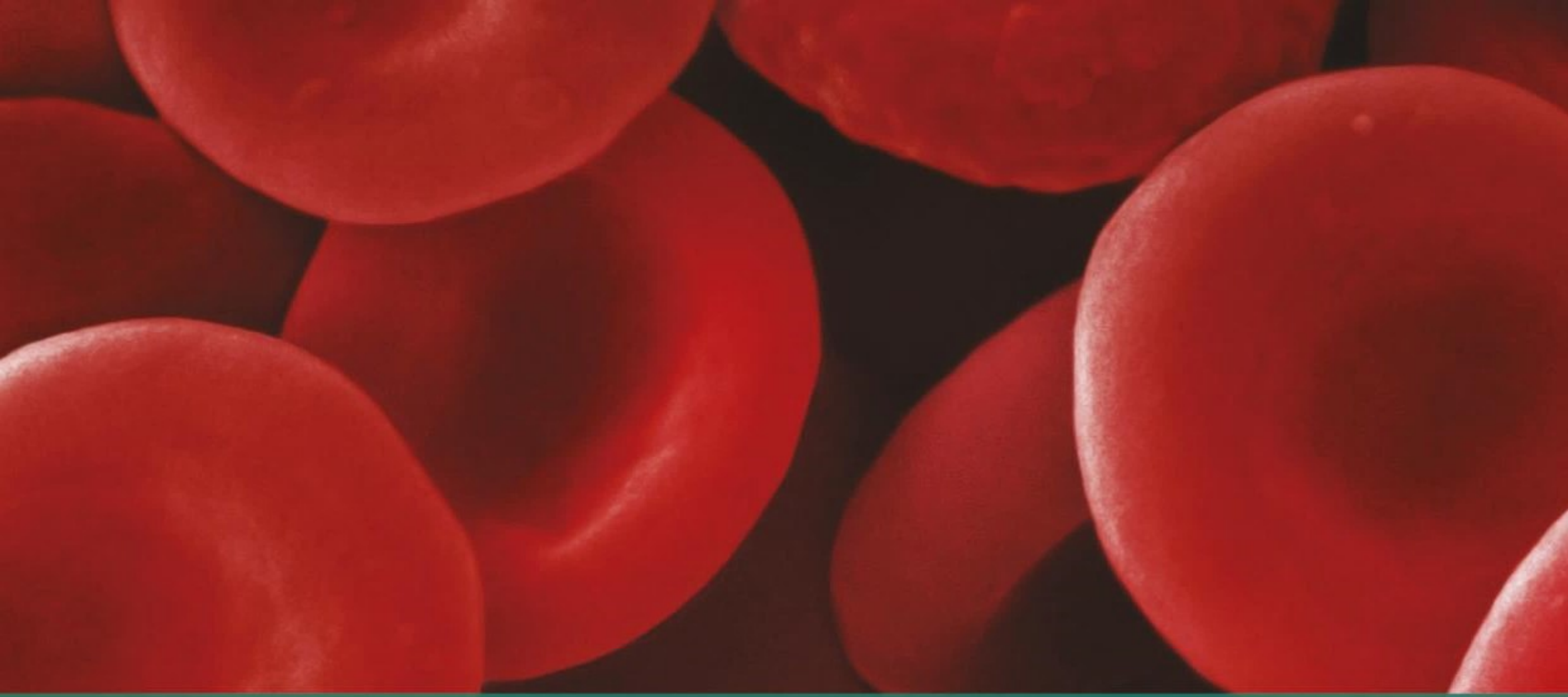
Name .... Class .... Date ....

Cell division

Lesson	Aiming for 4		Aiming for 6		Aiming for 8	
B2.1 Cell division	I can state that human body cells have 46 chromosomes and gametes have 23.	☐	I can explain why chromosomes in body cells are normally found in pairs.	☐	I can explain why genetic material must be doubled during mitosis.	☐
	I can state that mitosis is a stage in cell division.	☐	I can describe situations where mitosis is occurring.	☐	I can explain in detail what happens at each stage of the cell cycle.	☐
	I can state the meaning of most of the keywords – mitosis, chromosomes, gene, gametes.	☐	I can use the keywords to describe the process of mitosis.	☐	I can use the keywords to write detailed explanations on why mitosis is an important process in living things and how characteristics are inherited.	☐
B2.2 Growth and differentiation	I can define the terms growth and differentiation.	☐	I can describe the importance of cell differentiation in multicellular organisms.	☐	I can compare and contrast differentiation in plants and animals.	☐
	I can state why plant clones are genetically identical to each other.	☐	I can explain how using tissue culture creates a clone of a plant.	☐	I can explain why it is easier to clone a plant compared to an animal.	☐
	I can attempt to clone a plant by using apparatus correctly.	☐	I can attempt to clone a plant by using the apparatus correctly and following safety rules.	☐	I can explain and carry out a practical accurately and safely in order to successfully clone a plant.	☐
B2.3 Stem cells	I can state that a stem cell is a cell that is not differentiated.	☐	I can describe differences between embryonic and adult stem cells.	☐	I can explain why embryonic stem cells are more useful for helping medical conditions.	☐
	I can state that plant stem cells can be used to create clones.	[illegible]	I can explain why plant clones are [illegible]	[illegible]	I can write a well-structured article about [illegible]	☐

Check your own progress with the self-assessment checklists.

If you are a teacher reading this, Kerboodle also has plenty of practical support, assessment resources, answers to the questions in the book, and a digital markbook along with full teacher support for practicals and the worksheets, which include suggestions on how to support and stretch your students. All of the resources that you need are pulled together into ready-to-use lesson presentations.



1 Cells and organisation

Living things range from microscopic organisms, to blue whales that can be 30 metres long, and to giant redwood trees that tower over 100 metres. Big or small, all living things are built up of basic building blocks known as cells. Every cell contains a similar mixture of chemical elements combined to make up the molecules of life.

Some organisms are single cells. Many others, including ourselves, contain billions of individual cells working together. In this section you will learn about the characteristics of these cells, and look at how they are organised so that even the largest organisms can carry out all of the functions of life.

Key questions

- What are the differences between eukaryotic and prokaryotic cells?
- How can stem cells be used in human medicine?
- What factors affect how an enzyme works?
- How can a stent prevent a heart attack?

Making connections

- You will learn how lifestyle factors such as smoking, alcohol, and exercise levels affect the health of your heart, lungs, and other organs in in **B7 Non-communicable diseases**
- You will learn about how eukaryotic and prokaryotic organisms have evolved over time, how they are classified, and how they are still evolving in **B15 Genetics and evolution**.
- You will find out much more about the role of bacteria in animal and plant diseases in **B5 Communicable diseases**, about their importance in genetic engineering and evolution in **B14 Variation and evolution**, and about their importance in decomposition in **B17 Organising an ecosystem**.

I already know...

I will learn...

I already know...	I will learn...
What cells look like under a light microscope.	What we can see under the electron microscope – and how to calculate magnification.
The similarities and differences between plant and animal cells.	The similarities and differences between prokaryotic and eukaryotic cells and orders of magnitude.
The role of diffusion in the movement of materials in and between cells.	The roles of osmosis and active transport in the movement of materials in and between cells.
Reproduction in animals and plants.	The type of cell division that forms the gametes and the way normal body cells grow and divide
The importance of the digestive system.	The way the structure of enzymes is related to their function.
The basic structure and function of the human gas exchange system.	Surface area: volume ratios and the adaptations of the alveoli of the lungs for effective gas exchange.
The mechanism of breathing.	The importance of ventilating the lungs and the gills of fish to maintain steep concentration gradients.
The role of the leaf stomata in gas exchange in plants.	How evaporation and transpiration are controlled in plants.

Required Practicals

Practical		Topic
1	Looking at cells	B1.2
3	Investigating osmosis in plant cells	B1.8
4	Food tests	B3.3
5	The effect of pH on the rate of reaction of amylase	B3.6

B 1 Cell structure and transport

1.1 The world of the microscope

Learning objectives

After this topic, you should know:

- how microscopy techniques have developed over time
- the differences in magnification and resolution between a light microscope and an electron microscope
- how to calculate the magnification, real size, and image size of a specimen.

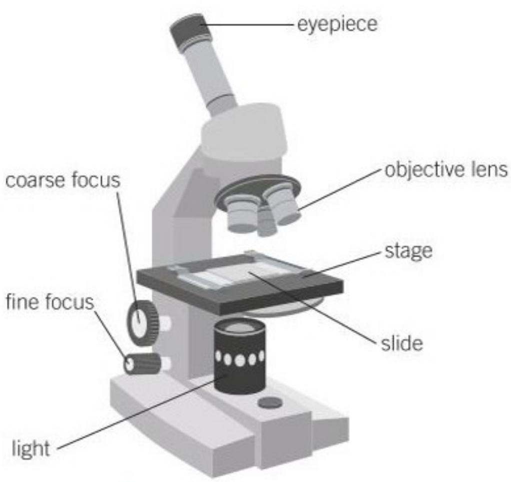


Figure 1 *A light microscope*

Living things are all made up of cells, but most cells are so small you can only see them using a microscope. It is important to grasp the units used for such tiny specimens before you start to look at them.

Using units

1 kilometre (km) = 1000 metres (m)

1 m = 100 centimetres (cm)

1 cm = 10 millimetres (mm)

1 mm = 1000 micrometres (μm)

1 μm = 1000 nanometres (nm) – so a nanometre is 0.000 000 001 metres (or written in standard form as 1×10^{-9} m).

The first light microscopes were developed in the mid-17th century. Their development has continued ever since and they are still widely used to look at cells. Light microscopes use a beam of light to form an image of an object and the best can magnify around 2000 times (×2000), although school microscopes usually only magnify several hundred times. They are relatively cheap, can be used almost anywhere, and can magnify live specimens (Figures 1 and 2).

The invention of the electron microscope in the 1930s allowed biologists to see and understand more about the subcellular structures inside cells. These instruments use a beam of electrons to form an image and can magnify objects up to around 2 000 000 times. Transmission electron microscopes give 2D images with very high magnification and resolution. Scanning electron microscopes give dramatic 3D images but lower magnifications (Figure 3). Electron microscopes are large, very expensive, and have to be kept in special temperature, pressure, and humidity-controlled rooms.

Calculating magnification

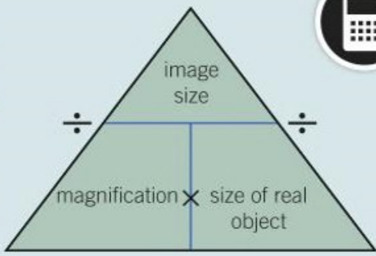
You can calculate the magnification you are using with a light microscope very simply. You multiply the magnification of the eyepiece lens by the magnification of the objective lens. So if your eyepiece lens is ×4 and your objective lens is ×10, your overall magnification is:

$4 \times 10 = \times 40$

When you label drawings made using a microscope, make it clear that the magnification you give is the magnification at which you looked at the specimen (eg., as viewed at ×40).

Calculating the size of an object

You will want to calculate the size of objects under the microscope. There is a simple formula for this, based on the magnification triangle.



As long as you know or can measure two of the factors, you can find the third.

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

For example, if you know you are working at magnification ×40, and the image of the cell you are looking at measures 1 mm, you can work out the actual diameter of the cell:

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

so

$$= \frac{1}{40}\,\text{mm} = 0.025\,\text{mm or } 25\,\mu\text{m}$$

Your cell has a diameter of **25 µm**.

Magnifying and resolving power

Microscopes are useful because they magnify things, making them look bigger. The height of an average person magnified by one of the best light microscopes would look about 3.5 km, and by an electron microscope about 3500 km. There is, however, a minimum distance between two objects when you can see them clearly as two separate things. If they are closer together than this, they appear as one object. Resolution is the ability to distinguish between two separate points and it is the **resolving power** of a microscope that affects how much detail it can show. A light microscope has a resolving power of about 200 nm, a scanning electron microscope of about 10 nm and a transmission electron microscope of about 0.2 nm – that is approximately the distance apart of two atoms in a solid substance!

1 Name one advantage and one disadvantage of using:
a a light microscope [2 marks] **b** an electron microscope. [2 marks]

2 a A student measured the diameter of a human capillary on a micrograph. The image measures 5 mm and the student knows the magnification is ×1000. How many micrometres is the diameter of the capillary? [3 marks]

b A student is told the image of the cell has a diameter of 800 µm. The actual cell has a diameter of 20 µm. At what magnification has the cell been observed? [2 marks]

3 Evaluate the use of an electron microscope and a light microscope, giving one example where each type of microscope might be used. [6 marks]

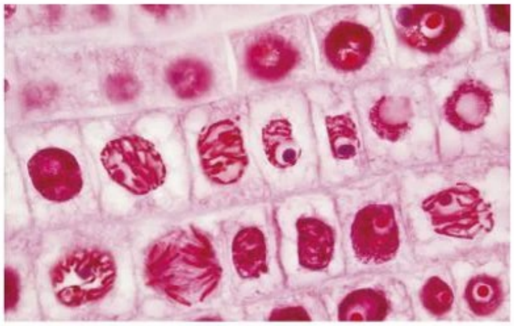


Figure 2 *Onion cells dividing as seen through a light microscope – magnification ×570*

Figure 3 *Chromosomes during cell division seen with a scanning electron microscope – magnification ×4500*

Synoptic links

You can learn more about writing very small or very large numbers in standard form in the Maths skills section in Topic M1b.

For more information on cell division look at Chapter B2.

Study tip

Make sure you can work out the magnification, the size of a cell, or the size of the image depending on the information you are given.

Key points

- Light microscopes magnify up to about ×2000, and have a resolving power of about 200 nm.
- Electron microscopes magnify up to about ×2 000 000, and have a resolving power of around 0.2 nm.
- $\text{magnification} = \frac{\text{size of image}}{\text{size of real object}}$

B1.2 Animal and plant cells

Learning objectives

After this topic, you should know:

- the main parts of animal cells
- the similarities and differences between plant and animal cells.

The cells that make up your body are typical animal cells. All cells have some features in common. You can see these features clearly in animal cells.

Animal cells – structure and function

The structure and functions of the parts that make up a cell have been made clear by the electron microscope (Figure 1). You will learn more about how their structure relates to their functions as you study more about specific organ systems during your GCSE Biology course. An average animal cell is around 10–30 μm long (so it would take 100 000–300 000 cells to line up along the length of a metre ruler). Human beings are animals so human cells are just like most other animal cells, and you will see exactly the same structures inside them.

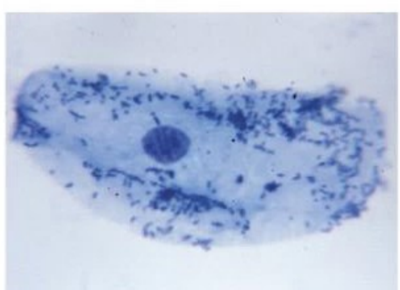
Synoptic link

You will find out more about classifying the living world in Chapter B16.

- The **nucleus** – controls all the activities of the cell and is surrounded by the nuclear membrane. It contains the genes on the chromosomes that carry the instructions for making the proteins needed to build new cells or new organisms. The average diameter is around 10 μm.
- The **cytoplasm** – a liquid gel in which the organelles are suspended and where most of the chemical reactions needed for life take place.
- The **cell membrane** – controls the passage of substances such as glucose and mineral ions into the cell. It also controls the movement of substances such as urea or hormones out of the cell.
- The **mitochondria** – structures in the cytoplasm where aerobic respiration takes place, releasing energy for the cell. They are very small: 1–2 μm in length and only 0.2–0.7 μm in diameter.
- The **ribosomes** – where protein synthesis takes place, making all the proteins needed in the cell.

Go further

The ultrastructure of a cell – the details you can see under an electron microscope – includes structures such as the cytoskeleton, the Golgi apparatus, and the rough and smooth endoplasmic reticulum. They support and move the cell, modify and package proteins and lipids, and produce the chemicals that control the way your body works.



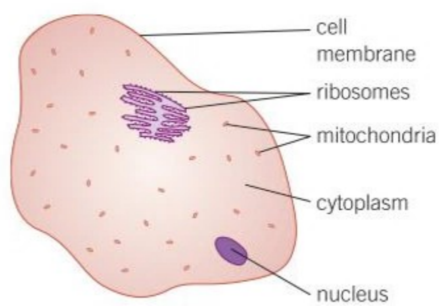


Figure 1 *Diagrams of cells are much easier to understand than the real thing seen under a microscope. This picture shows a simple animal cheek cell magnified ×1350 times under a light microscope. This is the way a model animal cell is drawn to show the main features common to most living cells*

Study tip

Learn the parts of the cells shown on these diagrams, and their functions.

Plant cells – structure and function

Plants are very different organisms from animals. They make their own food by photosynthesis. They do not move their whole bodies about from one place to another. Plant cells are often rather bigger than animal cells – they range from 10 to 100 μm in length.

Synoptic link

For more information on photosynthesis, look at Topic B8.1.

Plant cells have all the features of a typical animal cell, but they also contain features that are needed for their very different functions (Figures 2 and 3). **Algae** are simple aquatic organisms. They also make their own food by photosynthesis and have many similar features to plant cells. For centuries they were classified as plants, but now they are classified as part of a different kingdom – the protista.

Figure 2 *Algal cells contain a nucleus and chloroplasts so that they can photosynthesise*

All plant and algal cells have a **cell wall** made of **cellulose** that strengthens the cell and gives it support.

Many (but not all) plant cells also have these other features:

- **Chloroplasts** are found in all the green parts of a plant. They are green because they contain the green substance **chlorophyll**. Chlorophyll absorbs light so the plant can make food by photosynthesis. Each chloroplast is around 3–5 μm long. Root cells do not have chloroplasts because they are underground and do not photosynthesise.
- A **permanent vacuole** is a space in the cytoplasm filled with cell sap. This is important for keeping the cells rigid to support the plant.

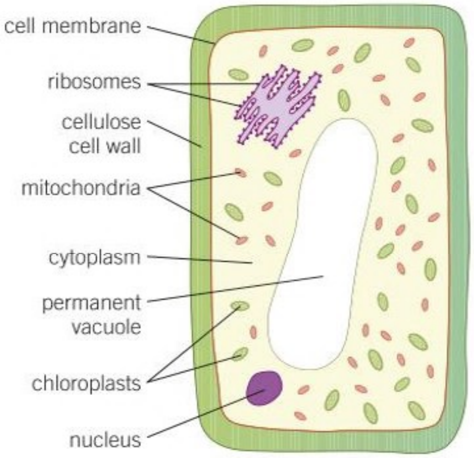


Figure 3 *A plant cell has many features in common with an animal cell, as well as other features that are unique to plants*

1 a Name the main structures you would expect to find in a human cell. [5 marks]

b Name the three extra features that may be found in plant cells but not animal cells. [3 marks]

c Describe the main functions of these three extra structures. [3 marks]

2 Suggest why the nucleus and the mitochondria are so important in all cells. [4 marks]

3 Chloroplasts are found in many plant cells but not all of them. Suggest two types of plant cells that are unlikely to have chloroplasts and in each case explain why they have none. [4 marks]

Looking at cells

Set up a microscope and observe, draw, and label examples of animal cells (e.g., cheek cells, Figure 1), algal cells (e.g., Figure 2) and plant cells (e.g., from onions or *Elodea*). In plant cells you should see the cell wall, the cytoplasm, and sometimes a vacuole. You will see chloroplasts in the *Elodea*, but not in the onion cells because they do not photosynthesise. Always show a scale magnification on your drawings.

Safety: if preparing your own cheek cells, please follow safety procedures.

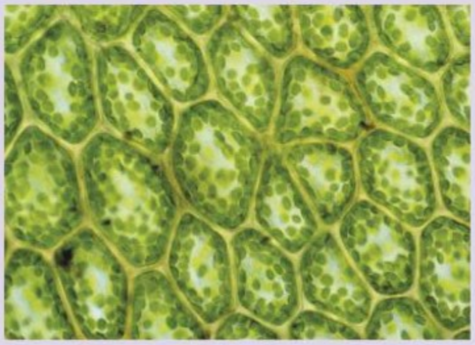


Figure 4 *Some of the common features of plant cells show up well under the light microscope. Here, the features are magnified ×40*

Study tip

Remember that not all plant cells have chloroplasts.

Do not confuse chloroplasts and chlorophyll.

Key points

- Animal cell features common to all cells – a nucleus, cytoplasm, cell membrane, mitochondria, and ribosomes.
- Plant and algal cells contain all the structures seen in animal cells as well as a cellulose cell wall.
- Many plant cells also contain chloroplasts and a permanent vacuole filled with sap.

B1.3 Eukaryotic and prokaryotic cells

Learning objectives

After this topic, you should know:

- the similarities and differences between eukaryotic cells and prokaryotic cells
- how bacteria compare to animal and plant cells
- the size and scale of cells including order of magnitude calculations.

Eukaryotic cells

Animal and plant cells are examples of **eukaryotic cells**. Eukaryotic cells all have a cell membrane, cytoplasm, and genetic material that is enclosed in a nucleus.

The genetic material is a chemical called DNA and this forms structures called chromosomes that are contained within the nucleus. All animals (including human beings), plants, fungi, and protista are eukaryotes.

Prokaryotes

Bacteria are single-celled living organisms. They are examples of prokaryotes. At 0.2–2.0 μm in length prokaryotes are 1–2 orders of magnitude smaller than eukaryotes. You could fit hundreds of thousands of bacteria on to the full stop at the end of this sentence, so you cannot see individual bacteria without a powerful microscope. When you culture bacteria on an agar plate, you grow many millions of bacteria. This enables you to see the bacterial colony with your naked eye.

Bacteria have cytoplasm and a cell membrane surrounded by a cell wall, but the cell wall does not contain the cellulose you see in plant cells. In prokaryotic cells the genetic material is not enclosed in a nucleus. The bacterial chromosome is a single DNA loop found free in the cytoplasm.

Prokaryotic cells may also contain extra small rings of DNA called plasmids. Plasmids code for very specific features such as antibiotic resistance.

Synoptic link

You will learn more about growing colonies of bacteria on agar plates in Topic B5.3. You will learn more about bacteria that cause disease in Topic B5.7, and about bacteria that are important in the environment in Topic B17.2 and Topic B17.3.

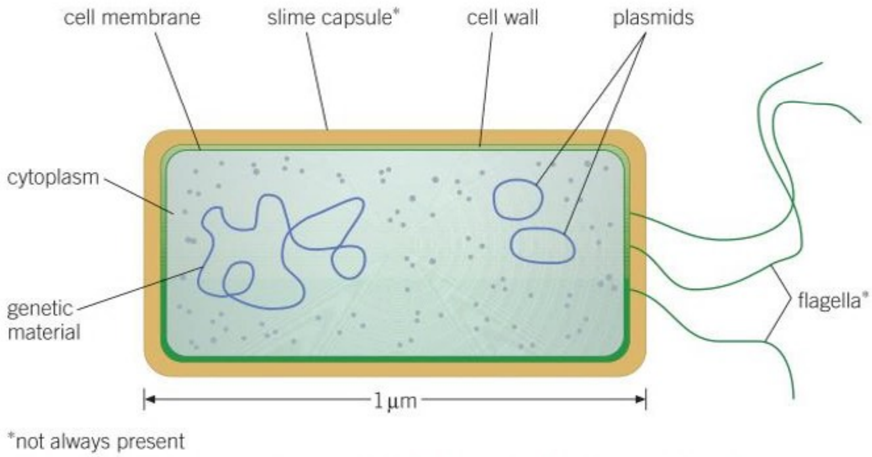


Figure 1 *Bacteria come in a variety of shapes, but they all have the same basic structure*

Some bacteria have a protective slime capsule around the outside of the cell wall. Some types of bacterium have at least one flagellum (plural: flagella), that is, a long protein strand that lashes about. These bacteria use their flagella to move themselves around.

Many bacteria have little or no effect on other organisms and many are very useful.

Go further

The plasmids found in bacteria are used extensively in genetic engineering to carry new genes into the genetic material of other organisms, ranging from bananas to sheep.

Some bacteria are harmful. Bacteria can cause diseases in humans and other animals and also in plants. They can also decompose and destroy stored food.

Relative sizes

In cell biology it is easy to forget just how small everything is – and how much bigger some cells are than others. It is also important to remember just how large the organisms built up from individual cells can be. Figure 2 shows you some relative sizes.

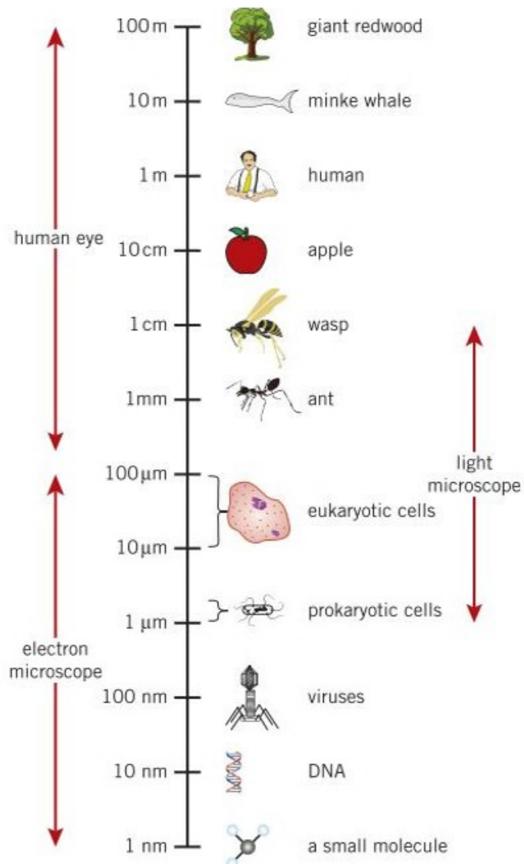


Figure 2 *The relative sizes of different cells and whole organisms and how they can be seen*

Orders of magnitude

Orders of magnitude are used to make approximate comparisons between numbers or objects. If one number is about 10 times bigger than another, it is an order of magnitude bigger. You show orders of magnitude using powers of 10. If one cell or organelle is 10 times bigger than another, it is an order of magnitude bigger or 10^1. If it is approximately 100 times bigger it is two orders of magnitude bigger or 10^2.

If you have two numbers to compare, as a rule of thumb you can work out orders of magnitude as follows:

If the bigger number divided by the smaller number is less than 10, then they are the same order of magnitude.

If the bigger number divided by the smaller number is around 10, then it is 10^1 or an order of magnitude bigger.

If the bigger number divided by the smaller number is around 100, then it is two orders of magnitude or 10^2 bigger.

Example:

A small animal cell has a length of around 10 µm. A large plant cell has a length of around 100 µm.

$$\frac{100}{10} = 10$$

So, a large plant cell is an order of magnitude or 10^1 bigger than a small animal cell.

Study tip

Be clear about the similarities and differences between animal, plant, and bacterial cells and between eukaryotic cells and prokaryotic cells.

1 a Describe the difference between the genetic material in a prokaryotic cell and the genetic material in the eukaryotic cell. [2 marks]

b i Describe what flagella are. [1 mark]

ii Name one use of flagella in a prokaryote. [1 mark]

2 A cell nucleus has an average length of 6 µm. Calculate the order of magnitude comparison between the nucleus of a cell and:

a a small animal cell [2 marks] **b** a large plant cell. [2 marks]

3 Describe the similarities and differences between the features found in prokaryotic and eukaryotic plant and animal cells. [6 marks]

Key points

- Eukaryotic cells all have a cell membrane, cytoplasm, and genetic material enclosed in a nucleus.
- Prokaryotic cells consist of cytoplasm and a cell membrane surrounded by a cell wall. The genetic material is not in a distinct nucleus. It forms a single DNA loop. Prokaryotes may contain one or more extra small rings of DNA called plasmids.
- Bacteria are all prokaryotes.

B1.4 Specialisation in animal cells

Learning objectives

After this topic, you should know:

- how cells differentiate to form specialised cells
- animal cells may be specialised to carry out a particular function
- how the structure of different types of animal cells relates to their function.

Synoptic links

You can find out much more about the organisation of specialised cells into tissues, organs and organ systems in Topic B3.1 and Topic B3.2.

Synoptic link

You can find out more about specialised nerve cells in Chapter B10.

Observing specialised cells

Try looking at different specialised cells under a microscope.

When you look at a specialised cell, there are two useful questions you can ask yourself:

- How is this cell different in structure from a generalised cell?
- How does the difference in structure help the cell to carry out its function?

Although the smallest living organisms are only single cells, they can carry out all of the functions of life. Most organisms are bigger and are made up of lots of cells. Some of these cells become specialised to carry out particular jobs.

As an organism develops, cells differentiate to form different types of specialised cells. Most types of animal cells differentiate at an early stage of development, whereas many types of plant cells retain the ability to differentiate throughout life. As a cell differentiates, it gets different sub-cellular structures that enable it to carry out a particular function. It has become a specialised cell. Some specialised cells, such as egg and sperm cells, work individually. Others are adapted to work as part of a tissue, an organ, or a whole organism.

Nerve cells

Nerve cells are specialised to carry electrical impulses around the body of an animal (Figure 1). They provide a rapid communication system between the different parts of the body. They have several adaptations including:

- Lots of dendrites to make connections to other nerve cells.
- An axon that carries the nerve impulse from one place to another. They can be very long – the axon of a nerve cell in a blue whale can be up to 25 m long! The longest axon in your body runs from the base of your spine to your big toe.
- The nerve endings or synapses are adapted to pass the impulses to another cell or between a nerve cell and a muscle in the body using special transmitter chemicals. They contain lots of mitochondria to provide the energy needed to make the transmitter chemicals.

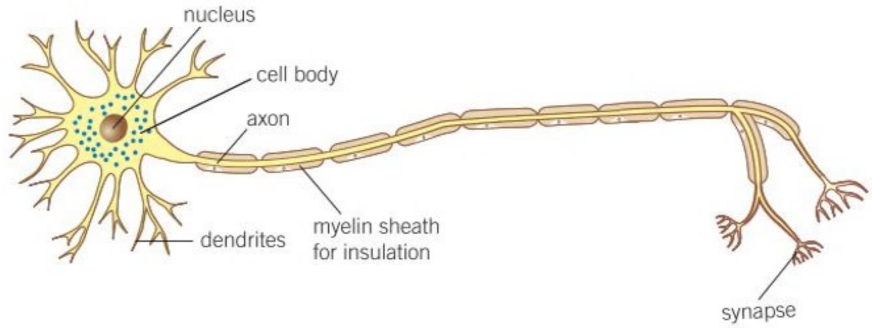


Figure 1 *A nerve cell is specialised to carry electrical impulses from one part of the body to another*

Muscle cells

Muscle cells are specialised cells that can contract and relax. Striated (striped) muscle cells work together in tissues called muscles (Figure 2). Muscles contract and relax in pairs to move the bones of the skeleton, so vertebrates can move on land and in water, and in some cases fly. Smooth muscle cells form one of the layers of tissue in your digestive system and they contract to squeeze the food through your gut.

Striated muscle cells have three main adaptations:

- They contain special proteins that slide over each other making the fibres contract.
- They contain many mitochondria to transfer the energy needed for the chemical reactions that take place as the cells contract and relax.
- They can store glycogen, a chemical that can be broken down and used in cellular respiration by the mitochondria to transfer the energy needed for the fibres to contract.

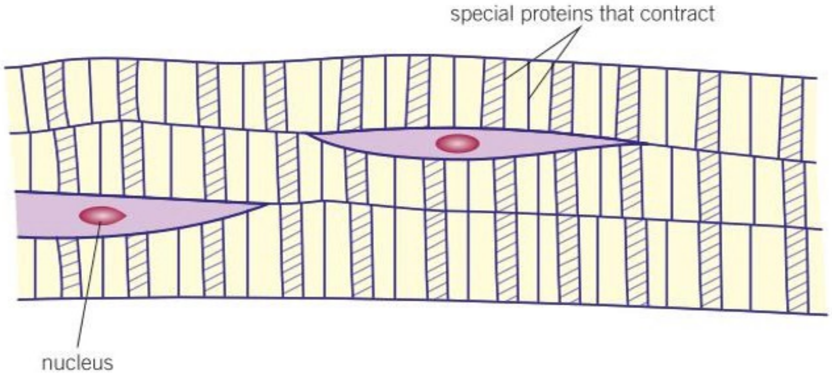


Figure 2 *A striated muscle cell is specialised to contract and relax*

Sperm cells

Sperm cells are usually released a long way from the egg they are going to fertilise. They contain the genetic information from the male parent. Depending on the type of animal, sperm cells need to move through water or the female reproductive system to reach an egg. Then they have to break into the egg.

Sperm cells have several adaptations to make all this possible (Figure 3):

- A long tail whips from side to side to help move the sperm through water or the female reproductive system.
- The middle section is full of mitochondria, which transfer the energy needed for the tail to work.
- The acrosome stores digestive enzymes for breaking down the outer layers of the egg.
- A large nucleus contains the genetic information to be passed on.

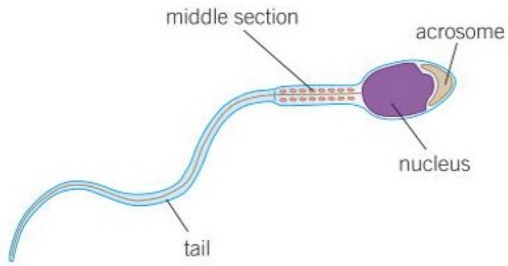


Figure 3 *A sperm cell*

1 Name one adaptation for each of the following specialised animal cells. Describe how this adaptation helps the cell carry out its function:

a nerve cell [2 marks]

b muscle cell [2 marks]

c sperm cell [2 marks]

2 Cone cells are specialised nerve cells in the eye. They contain a chemical that changes in coloured light. As a result of the change, an impulse is sent along another nerve cell to the brain. Cone cells usually contain many mitochondria. Suggest why this is an important adaptation. [4 marks]

3 Describe the features you would look for to decide on the function of an unknown specialised animal cell. [6 marks]

Key points

- As an organism develops, cells differentiate to form different types of cells.
- As an animal cell differentiates to form a specialised cell it acquires different sub-cellular structures to enable it to carry out a certain function.
- Examples of specialised animal cells are nerve cells, muscle cells, and sperm cells.
- Animal cells may be specialised to function within a tissue, an organ, organ systems, or whole organisms.

B1.5 Specialisation in plant cells

Learning objectives

After this topic, you should know:

- how plant cells may be specialised to carry out a particular function
- how the structure of different types of plant cells relates to their function.

Animals are not the only organisms to have cells specialised for a particular function within a tissue or an organ. Plants also have very specialised cells with clear adaptations for the job they carry out. Here are four examples.

Root hair cells

You find root hair cells close to the tips of growing roots. Plants need to take in lots of water (and dissolved mineral ions). The root hair cells help them to take up water and mineral ions more efficiently. Root hair cells are always relatively close to the xylem tissue. The xylem tissue carries water and mineral ions up into the rest of the plant. Mineral ions are moved into the root hair cell by active transport (Topic B1.9).

Root hair cells (Figure 1) have three main adaptations:

- They greatly increase the surface area available for water to move into the cell.
- They have a large permanent vacuole that speeds up the movement of water by osmosis from the soil across the root hair cell.
- They have many mitochondria that transfer the energy needed for the active transport of mineral ions into the root hair cells.

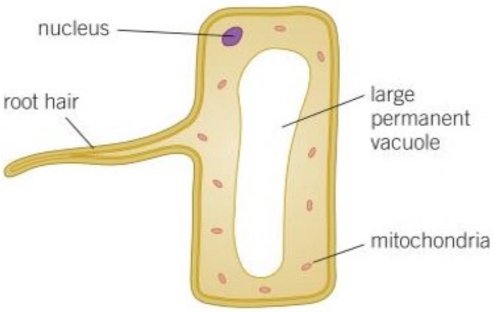


Figure 1 *A root hair cell*

Photosynthetic cells

One of the ways plants differ from animals is that plants can make their own food by photosynthesis. There are lots of plant cells that can carry out photosynthesis – and lots that cannot. Photosynthetic cells (Figure 2) usually have a number of adaptations including:

- They contain specialised green structures called chloroplasts containing chlorophyll that trap the light needed for photosynthesis.
- They are usually positioned in continuous layers in the leaves and outer layers of the stem of a plant so they absorb as much light as possible.
- They have a large permanent vacuole that helps keep the cell rigid as a result of osmosis (Topic B1.8). When lots of these rigid cells are arranged together to form photosynthetic tissue they help support the stem. They also keep the leaf spread out so it can capture as much light as possible.

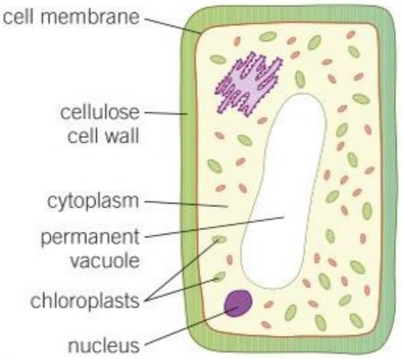


Figure 2 *A photosynthetic plant cell*

Synoptic link

You will learn much more about photosynthesis in Chapter B8.

Xylem cells

Xylem is the transport tissue in plants that carries water and mineral ions from the roots to the highest leaves and shoots. The xylem is also important in supporting the plant. The xylem is made up of xylem cells (Figure 3) that are adapted to their functions in two main ways:

- The xylem cells are alive when they are first formed but a special chemical called lignin builds up in spirals in the cell walls. The cells die and form long hollow tubes that allow water and mineral ions to move easily through them, from one end of the plant to the other.

- The spirals and rings of lignin in the xylem cells make them very strong and help them withstand the pressure of water moving up the plant. They also help support the plant stem.

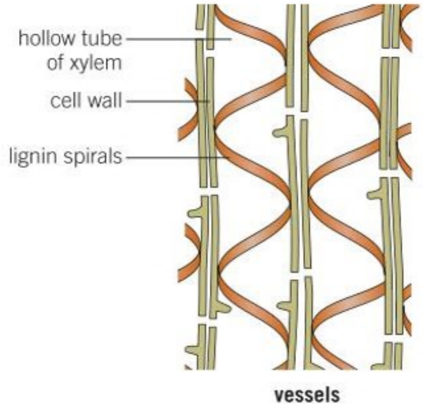


Figure 3 *The adaptations of xylem cells*

Synoptic link

You will learn more about the movement of water up the xylem and the process of transpiration in Chapter B4.

Phloem cells

Phloem is the specialised transport tissue that carries the food made by photosynthesis around the body of the plant. It is made up of phloem cells that form tubes rather like xylem cells, but phloem cells do not become lignified and die. The dissolved food can move up and down the phloem tubes to where it is needed. The adaptations of the phloem cells (Figure 4) include:

- The cell walls between the cells break down to form special sieve plates. These allow water carrying dissolved food to move freely up and down the tubes to where it is needed.

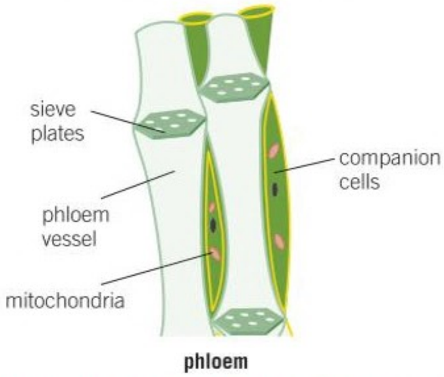


Figure 4 *The adaptations of phloem cells*

- Phloem cells lose a lot of their internal structures but they are supported by companion cells that help to keep them alive. The mitochondria of the companion cells transfer the energy needed to move dissolved food up and down the plant in phloem.

1 Name one adaptation for each of the following specialised plant cells. Describe how this adaptation helps the cell carry out its function:
a root hair cell [2 marks]
b xylem cell [2 marks]
c phloem cell [2 marks]
d photosynthetic cell [2 marks]

2 Suggest why a cell within the trunk of a tree cannot carry out photosynthesis. [2 marks]

3 Describe the features you would look for to decide on the function of an unknown specialised plant cell. [6 marks]

Key points

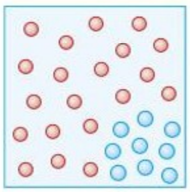
- Plant cells may be specialised to carry out a particular function.
- Examples of specialised plant cells are root hair cells, photosynthetic cells, xylem cells, and phloem cells
- Plant cells may be specialised to function within tissues, organs, organ systems, or whole organisms.

B1.6 Diffusion

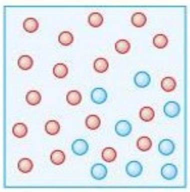
Learning objectives

After this topic, you should know:

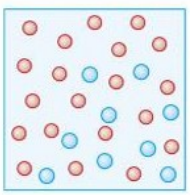
- how diffusion takes place and why it is important in living organisms
- what affects the rate of diffusion.



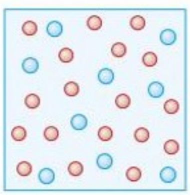
At the moment when the blue particles are added to the red particles they are not mixed at all



As the particles move randomly, the blue ones begin to mix with the red ones



As the particles move and spread out, they bump into each other. This helps them to keep spreading randomly



Eventually, the particles are completely mixed and diffusion is complete, although they do continue to move randomly

Figure 1 *The random movement of particles results in substances spreading out, or diffusing, from an area of higher concentration to an area of lower concentration*

Study tip

Particles move randomly, but the net movement is from a region of high concentration to a region of low concentration.

Your cells need to take in substances such as glucose and oxygen for respiration. They also need to get rid of waste products, and chemicals that are needed elsewhere in your body. Dissolved substances and gases can move into and out of your cells across the cell membrane. One of the main ways in which they move is by **diffusion**.

Diffusion

Diffusion is the spreading out of the particles of a gas, or of any substance in solution (a solute). This results in the net movement (overall movement) of particles. The net movement is from an area of higher concentration to an area of lower concentration of the particle. It takes place because of the random movement of the particles (molecules or ions). The motion of the particles causes them to bump into each other, and this moves them all around.

Imagine a room containing a group of boys on one side and a group of girls on the other. If everyone closes their eyes and moves around briskly but randomly, they will bump into each other. They will scatter until the room contains a mixture of boys and girls. This gives you a good model of diffusion (see Figure 1).

Rates of diffusion

If there is a big difference in concentration between two areas, diffusion will take place quickly. Many particles will move randomly towards the area of low concentration. Only relatively few will move randomly in the other direction.

However, if there is only a small difference in concentration between two areas, the net movement by diffusion will be quite slow. The number of particles moving into the area of lower concentration by random movement will only be slightly more than the number of particles that are leaving the area.

net movement = particles moving in − particles moving out

In general, the greater the difference in concentration, the faster the rate of diffusion. This difference between two areas of concentration is called the concentration gradient. The bigger the difference, the steeper the concentration gradient and the faster the rate of diffusion. In other words, diffusion occurs *down* a concentration gradient.

Temperature also affects the rate of diffusion. An increase in temperature means the particles in a gas or a solution move around more quickly. When this happens, diffusion takes place more rapidly as the random movement of the particles speeds up.

Diffusion in living organisms

Dissolved substances move into and out of your cells by diffusion across the cell membrane. These include simple sugars, such as glucose, gases such as oxygen and carbon dioxide, and waste products such as urea from the breakdown of amino acids in your liver. The urea passes from the liver cells into the blood plasma and is excreted by the kidneys.

The oxygen you need for respiration passes from the air in your lungs into your red blood cells through the cell membranes by diffusion. The oxygen moves down a concentration gradient from a region of high oxygen concentration to a region of low oxygen concentration.

Oxygen then also moves by diffusion down a concentration gradient from the blood cells into the cells of the body where it is needed. Carbon dioxide moves out from the body cells into the red blood cells and then into the air in the lungs by diffusion down a concentration gradient in a similar way. The diffusion of oxygen and carbon dioxide in opposite directions in the lungs is known as gas exchange.

Individual cells may be adapted to make diffusion easier and more rapid. The most common adaptation is to increase the surface area of the cell membrane (Figure 2). By folding up the membrane of a cell, or the tissue lining an organ, the area over which diffusion can take place is greatly increased. Therefore the rate of diffusion is also greatly increased, so that much more of a substance moves in a given time.

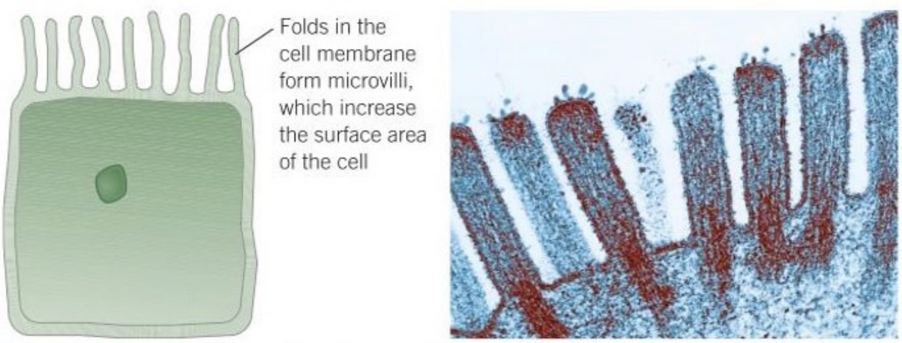


Figure 2 *An increase in the surface area of a cell membrane means diffusion can take place more quickly. This is an intestinal cell – magnification × 57 600*

1 Define the process of diffusion in terms of the particles involved. [2 marks]

2 **a** Explain why diffusion takes place faster when there is an increase in temperature. [3 marks]

b Explain why so many cells have folded membranes along at least one surface. [2 marks]

3 Describe the process of diffusion occurring in each of the following statements. Include any adaptations that are involved.

a Digested food products move from your gut into the bloodstream. [3 marks]

b Carbon dioxide moves from the blood in the capillaries of your lungs to the air in the lungs. [3 marks]

c Male moths can track down a mate from up to 3 miles away because of the special chemicals produced by the female. [3 marks]

Synoptic link

You will learn more about the excretion of urea by the kidney in Topic B12.2.

You will learn more about gas exchange in Topic B4.5.

Key points

- Diffusion is the spreading out of particles of any substance, in solution or a gas, resulting in a net movement from an area of higher concentration to an area of lower concentration, down a concentration gradient.
- The rate of diffusion is affected by the difference in concentrations, the temperature, and the available surface area.
- Dissolved substances such as glucose and urea and gases such as oxygen and carbon dioxide move in and out of cells by diffusion.

B1.7 Osmosis

Learning objectives

After this topic, you should know:

- how osmosis differs from diffusion
- why osmosis is so important in animal cells.

Study tip

Remember, any particles can diffuse from an area of high concentration to an area of low concentration, provided they are **soluble** and **small** enough to pass through the membrane.

Osmosis in organisms refers only to the diffusion of *water* molecules through the partially permeable cell membrane.

Investigating osmosis

You can make model cells using bags made of partially permeable membrane (see Figure 1). You can find out what happens to them if the concentrations of the solutions inside or outside the 'cell' change.

Diffusion takes place when particles can spread out freely from a higher to a lower concentration. However, the solutions inside cells are separated from those outside by the cell membrane. This membrane does not let all types of particles through. Membranes that only let some types of particles through are called **partially permeable membranes**.

How osmosis differs from diffusion

Partially permeable cell membranes let water move across them. Remember:

- A **dilute** solution of sugar contains a *high* concentration of water (the solvent). It has a *low* concentration of sugar (the solute).
- A **concentrated** sugar solution contains a relatively *low* concentration of water and a *high* concentration of sugar.

The cytoplasm of a cell is made up of chemicals dissolved in water inside a partially permeable cell membrane. The cytoplasm contains a fairly concentrated solution of salts and sugars. Water moves from a dilute solution (with a high concentration of water molecules) to a concentrated solution (with fewer water molecules in a given volume) across the membrane of the cell.

This special type of diffusion, where only water moves across a partially permeable membrane from a dilute solution to a concentrated solution is called **osmosis**.

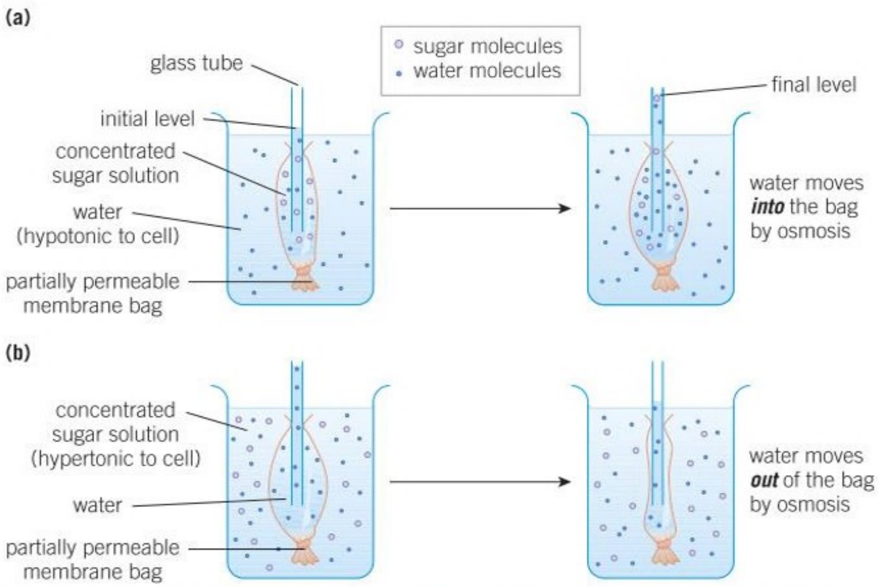


Figure 1 *A model of osmosis in a cell. In* (a) *the model cell is in a hypotonic solution. In* (b) *the model cell is in a hypertonic solution*

The concentration of solutes inside your body cells needs to stay at the same level for them to work properly. However, the concentration of the solutions outside your cells may be very different to the concentration inside them. This concentration gradient can cause water to move into or out of the cells by osmosis (see Figure 1).

- If the concentration of solutes in the solution outside the cell is **the same** as the internal concentration, the solution is **isotonic** to the cell.
- If the concentration of solutes in the solution outside the cell is **higher** than the internal concentration, the solution is **hypertonic** to the cell.
- If the concentration of solutes in the solution outside the cell is **lower** than the internal concentration, the solution is **hypotonic** to the cell.

Osmosis in animals

If a cell uses up water in its chemical reactions, the cytoplasm becomes more concentrated. The surrounding fluid becomes hypotonic to the cell and more water immediately moves in by osmosis.

If the cytoplasm becomes too dilute because more water is made in chemical reactions, the surrounding fluid becomes hypertonic to the cell and water leaves the cell by osmosis. Osmosis restores the balance in both cases.

However, osmosis can also cause big problems. If the solution outside the cell becomes much more dilute (hypotonic) than the cell contents, water will move in by osmosis. The cell will swell and may burst. If the solution outside the cell becomes much more concentrated (hypertonic) than the cell contents, water will move out of the cell by osmosis. The cytoplasm will become too concentrated and the cell will shrivel up and can no longer survive. Once you understand the effect osmosis can have on cells, the importance of maintaining constant internal conditions becomes clear.

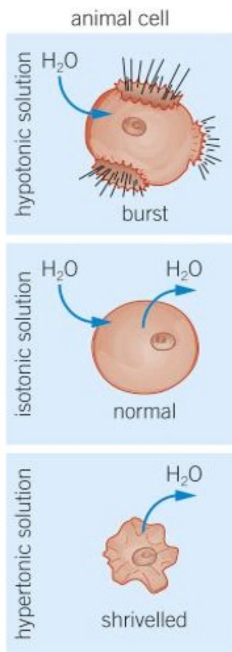


Figure 2 *Osmosis can have a dramatic effect on animal cells*

Study tip

When writing about osmosis, be careful to specify whether it is the concentration of water or of solutes that you are referring to.

Make sure you understand exactly what is meant by the terms isotonic, hypertonic, and hypotonic.

1 **a** Explain the difference between osmosis and diffusion. [2 marks]
b Explain how osmosis helps to maintain the cytoplasm of plant and body cells at a specific concentration. [2 marks]

2 **a** Define the following terms:
i isotonic solution [1 mark]
ii hypotonic solution [1 mark]
iii hypertonic solution. [1 mark]
b Explain why it is so important for the cells of the human body that the solute concentration of the fluid surrounding the cells is kept as constant as possible. [4 marks]

3 Animals that live in fresh water have a constant problem with their water balance. The single-celled organism called *Amoeba* has a special vacuole in its cell. The vacuole fills with water and then moves to the outside of the cell and bursts. A new vacuole starts forming straight away. Explain in terms of osmosis why the *Amoeba* needs one of these vacuoles. [4 marks]

Key points

- Osmosis is a special case of diffusion. It is the movement of water from a dilute to a more concentrated solution through a partially permeable membrane that allows water to pass through.
- Differences in the concentrations of solutions inside and outside a cell cause water to move into or out of the cell by osmosis.
- Animal cells can be damaged if the concentration outside the cell changes dramatically.

The basis of many experiments is to put plant tissue into different concentrations of salt solutions or sugar solutions. You can even use squash to give you the sugar solution. If plant tissue is placed in a hypotonic solution, water will move in to the cells by osmosis. If it is placed in a hypertonic solution, water will move out by osmosis. These changes can be measured by the effect they have on the tissue sample.

- Suggest why salt and sugar are used in osmosis experiments. How could you decide which gives the clearest results?
- Potato is commonly used as the experimental plant tissue. It can be cut into cylinders, rectangular 'chips' or smaller discs. Suggest why potato is so often used as a test plant tissue.
- Sweet potato and beetroot are other common sources of plant tissue for osmosis experiments – suggest possible advantages and disadvantages of using them. How could you determine which is the best experimental plant tissue?

Measuring changes in mass is a widely used method for investigating the uptake or loss of water from plant tissues by osmosis. You must take care not to include any liquid left on the outside of the plant tissue in your measurements as this can have a big effect on your results.

- Evaluate the possible advantages and disadvantages of cylinders, chips, or discs for assessing the effect of osmosis on plant tissue. How would you determine which method is the most effective?
- Investigate the effect of surface area on osmosis.
- Explain how you think the surface area of the plant tissue samples might affect osmosis.
- Plan an investigation to see if your ideas are right.
- Show your plan to your teacher and then carry out your investigation.

Safety: Take care when using cutting instruments.

Go further

Scientists have discovered ways of measuring the turgor pressure inside individual cells using very tiny probes. The pressures inside the root or leaf cell of a plant are far higher than human blood pressure, or even the pressure in a car tyre.

1 Define the term osmosis. [1 mark]

2 Students carried out an investigation into the effects of osmosis on plant tissues, placing three sets of beetroot cylinders in three different sugar solutions for 30 mins. One set had gained mass, another lost mass and the third set did not change. One student thought the last experiment hadn't worked. Another disagreed. Explain the results in terms of osmosis in plant cells. [6 marks]

3 Suggest and explain why osmosis is so important in the structural support systems of plants. [6 marks]

Key points

- Osmosis is important to maintain turgor in plant cells.
- There are a variety of practical investigations that can be used to show the effect of osmosis on plant tissues.

B1.9 Active transport

Learning objectives

After this topic, you should know:

- how active transport works
- the importance of active transport in cells.

People with cystic fibrosis have thick, sticky mucus in their lungs, gut and reproductive systems. This causes many different health problems and it happens because an active transport system in their mucus-producing cells does not work properly. Sometimes diffusion and osmosis are not enough.

All cells need to move substances in and out. Water often moves across the cell boundaries by osmosis. Dissolved substances also need to move in and out of cells. There are two main ways in which this happens:

- Substances move by diffusion, down a concentration gradient. This must be in the right direction to be useful to the cells.
- Sometimes the substances needed by a cell have to be moved against a concentration gradient, across a partially permeable membrane. This needs a special process called **active transport**.

Moving substances by active transport

Active transport allows cells to move substances from an area of low concentration to an area of high concentration. This movement is *against* the concentration gradient. As a result, cells can absorb ions from very dilute solutions. It also enables cells to move substances, such as sugars and ions, from one place to another through the cell membrane.

Energy is needed for the active transport system to carry a molecule across the membrane and then return to its original position. This energy is produced during cell respiration. Scientists have shown in a number of different cells that the rate of respiration and the rate of active transport are closely linked (Figure 1).

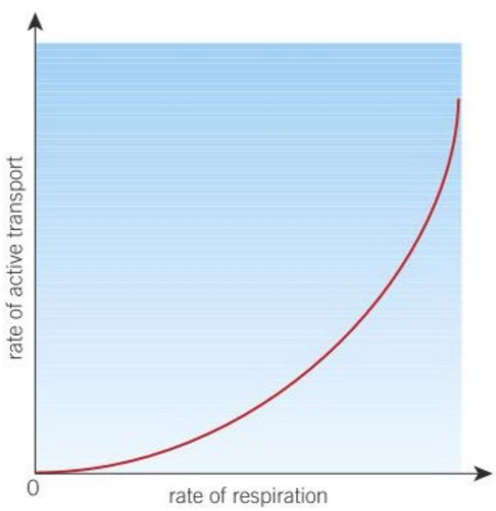


Figure 1 *The rate of active transport depends on the rate of respiration*

In other words, if a cell respires and releases a lot of energy, it can carry out lots of active transport. Examples include root hair cells in plants and the cells lining your gut. Cells involved in a lot of active transport usually have many mitochondria to release the energy they need.

The importance of active transport

Active transport is widely used in cells. There are some situations where it is particularly important. For example, mineral ions in the soil, such as nitrate ions, are usually found in very dilute solutions. These solutions are more dilute than the solution within the plant root hair cells. By using active transport, plants can absorb these mineral ions, even though it is against a concentration gradient (see Figure 2).

Sugar, such as glucose, is always actively absorbed out of your gut and kidney tubules into your blood. This is often done against a large concentration gradient.

For example, glucose is needed for cell respiration so it is important to get as much as possible out of the gut. The concentration of glucose in your blood is kept steady, so sometimes it is higher than the concentration of glucose in your gut. When this happens, active transport is used to move the glucose from your gut into your blood against the concentration gradient.

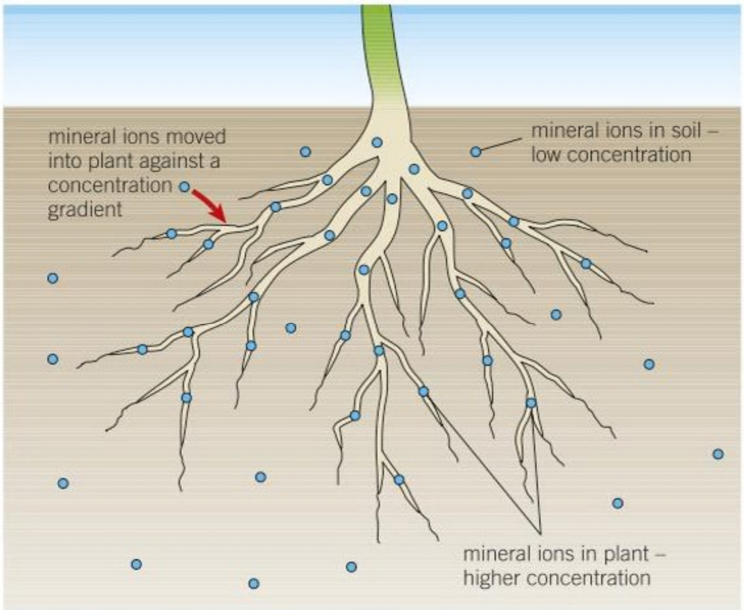


Figure 2 *Plants use active transport to move mineral ions from the soil into the roots against a concentration gradient*

Figure 3 *Some crocodiles have special salt glands in their tongues. These remove excess salt from the body against the concentration gradient by active transport. That's why members of the crocodile species Crocodylus porosus can live in estuaries and even the sea*

1 Describe how active transport works in a cell. [4 marks]

2 **a** Describe how active transport differs from diffusion and osmosis. [3 marks]

b Explain why cells that carry out a lot of active transport also usually have many mitochondria. [2 marks]

3 Explain fully why active transport is so important to:

a marine birds such as albatrosses that have special salt glands producing very salty liquid [2 marks]

b plants. [3 marks]

Synoptic links

You can find out more about cystic fibrosis in Topic B14.7, and about the absorption of glucose in the gut in Topic B3.6 and about the absorption of solutes in the kidney in Topic B12.3.

Study tip

Do not refer to movement *along* a concentration gradient. Always refer to movement as *down* a concentration gradient (from higher to lower) for diffusion or osmosis and *against* a concentration gradient (from lower to higher) for active transport.

Key points

- Active transport moves substances from a more dilute solution to a more concentrated solution (against a concentration gradient).
- Active transport uses energy released from food in respiration to provide the energy required.
- Active transport allows plant root hairs to absorb mineral ions required for healthy growth from very dilute solutions in the soil against a concentration gradient.
- Active transport enables sugar molecules used for cell respiration to be absorbed from lower concentrations in the gut into the blood where the concentration of sugar is higher.

B1.10 Exchanging materials

Learning objectives

After this topic, you should know:

- how the surface area to volume ratio varies depending on the size of an organism
- why large multicellular organisms need special systems for exchanging materials with the environment.

Synoptic links

You will use the idea of surface area to volume ratio when you study the adaptations of animals and plants for living in a variety of different habitats in Topics B16.7 and B16.8.

For many single-celled organisms, diffusion, osmosis, and active transport are all that is needed to exchange materials with their environment because they have a relatively large surface area compared to the volume of the cell. This allows sufficient transport of molecules into and out of the cell to meet the needs of the organism.

Surface area to volume ratio

The surface area to volume ratio is very important in biology. It makes a big difference to the way animals can exchange substances with the environment. Surface area to volume ratio is also important when you consider how energy is transferred by living organisms, and how water evaporates from the surfaces of plants and animals.

Surface area to volume ratio

The ratio of surface area to volume falls as objects get bigger. You can see this clearly in Figure 1. In a small object, the surface area to volume (SA:V) ratio is relatively large. This means that the diffusion distances are short and that simple diffusion is sufficient for the exchange of materials.

As organisms get bigger, the surface area to volume ratio falls. As the distances between the centre of the organism and the surface get bigger, simple diffusion is no longer enough to exchange materials between the cells and the environment.

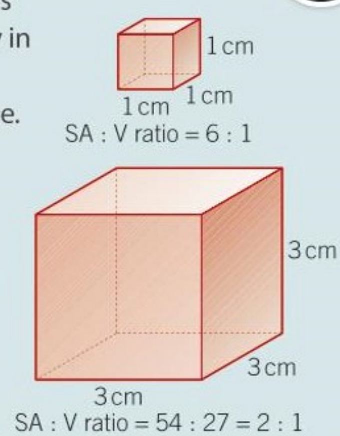


Figure 1 *Relationship of surface area to volume*

Getting bigger

As living organisms get bigger and more complex, their surface area to volume ratio gets smaller. This makes it increasingly difficult to exchange materials quickly enough with the outside world:

- Gases and food molecules can no longer reach every cell inside the organism by simple diffusion
- Metabolic waste cannot be removed fast enough to avoid poisoning the cells.

In many larger organisms, there are special surfaces where the exchange of materials takes place. These surfaces are adapted to be as effective as possible. You can find them in humans, in other animals, and in plants.

Synoptic links

You will find out much more about gas exchange in the lungs in Topic B4.5, and about the adaptations of the small intestine in Topic B3.2.

You can find out more about the transpiration stream in Topic B4.8.

Adaptations for exchanging materials

There are various adaptations to make the process of exchange more efficient. The effectiveness of an exchange surface can be increased by:

- having a large surface area over which exchange can take place
- having a thin membrane or being thin to provide a short diffusion path
- in animals, having an efficient blood supply moves the diffusing substances away from the exchange surfaces and maintains a steep concentration (diffusion) gradient
- in animals, being **ventilated** makes gas exchange more efficient by maintaining steep concentration gradients.

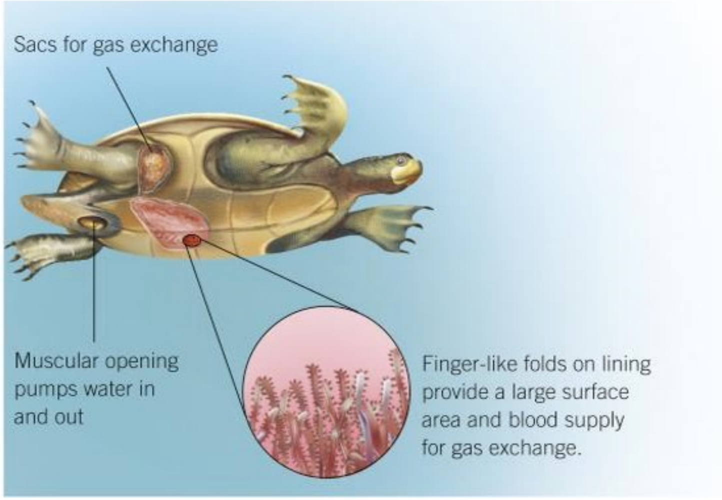


Figure 2 *Fitzroy river turtles can get oxygen from the water through a specialised excretory opening*

Examples of adaptations

Different organisms have very different adaptations for the exchange of materials. For example, the Australian Fitzroy river turtle (locally known as the bum-breathing turtle) can 'breathe' underwater (Figure 2). Inside the rear opening are two large sacs lined with finger-like folds which provide a large surface area and rich blood supply for gas exchange. The muscular opening pumps water in and out, ventilating the folds and maintaining a steep concentration gradient for gas exchange.

The human surface area to volume ratio is so low that the cells inside your body cannot possibly get the food and oxygen they need, or get rid of the waste they produce, by simple diffusion. Air is moved into and out of your lungs when you breathe, ventilating the millions of tiny air sacs called **alveoli**. The alveoli have an enormous surface area and a very rich blood supply, for effective gas exchange. The villi of the small intestine also provide a large surface area, short diffusion paths and a rich blood supply to make exchange of materials more effective.

Fish need to exchange oxygen and carbon dioxide between their blood and the water in which they swim. This happens across the gills, which are made up of stacks of thin filaments, each with a rich blood supply. Fish need a constant flow of water over their gills to maintain the concentration gradients needed for gas exchange. They get this by pumping water over the gills using a flap that covers the gills called the operculum.

Plant roots have a large surface area, made even bigger by the root hair cells, to make the uptake of water and mineral ions more efficient. Water constantly moves away from the roots in the transpiration stream, maintaining a steep concentration gradient in the cells.

Plant leaves are also modified to make gas and solute exchange as effective as possible. Flat, thin leaves, the presence of air spaces in the leaf tissues, and the **stomata** all help to provide a big surface area and maintain a steep concentration gradient for the diffusion of substances such as water, mineral ions, and carbon dioxide.

Key points

- Single-celled organisms have a relatively large surface area to volume ratio so all necessary exchanges with the environment take place over this surface.
- In multicellular organisms, many organs are specialised with effective exchange surfaces.
- Exchange surfaces usually have a large surface area and thin walls, which give short diffusion distances. In animals, exchange surfaces will have an efficient blood supply or, for gaseous exchange, be ventilated.

1 Describe two adaptations of an effective exchange surface. [2 marks]

2 Compare the gas exchange system of fish with that of the Australian Fitzroy river turtle shown in Figure 2. [5 marks]

3 **a** Explain how the surface area to volume ratio of an organism affects the way it exchanges materials with the environment. [2 marks]

b Describe the adaptations you would expect to see in effective exchange surfaces and explain the importance of each adaptation. [6 marks]

B1 Cell structure and transport

Summary questions

1 Describe the importance of microscopes in the development of our understanding of cell biology. [6 marks]

2 **a** Name the structures labelled A–F in the bacterial cell in Figure 1. [6 marks]

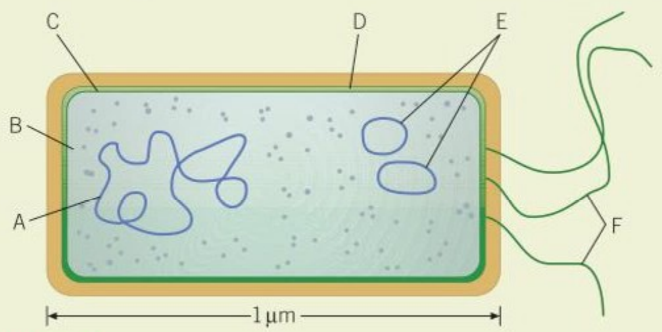


Figure 1

b Draw and label a typical eukaryotic cell to show the main characteristics and indicate the expected size range. [6 marks]

c Explain the similarities and differences between a bacterial cell and a plant cell. [6 marks]

d Some people think that structures found in plant and animal cells such as chloroplasts and mitochondria may have originally been free-living bacteria. Evaluate this possibility using the relative sizes of prokaryotic cells, eukaryotic cells, and eukaryotic organelles to support the argument. [5 marks]

3 **a** Give one similarity and one difference between diffusion and osmosis. [2 marks]

b Give one similarity and one difference between diffusion and active transport. [2 marks]

c In an experiment to investigate osmosis, two Visking tubing bags were set up, with sugar solution inside the bags and water outside the bags. Bag A was kept at 20 °C and bag B was kept at 30 °C (Figure 2). Describe what you would expect to happen and explain it in terms of osmosis and particle movements. [5 marks]

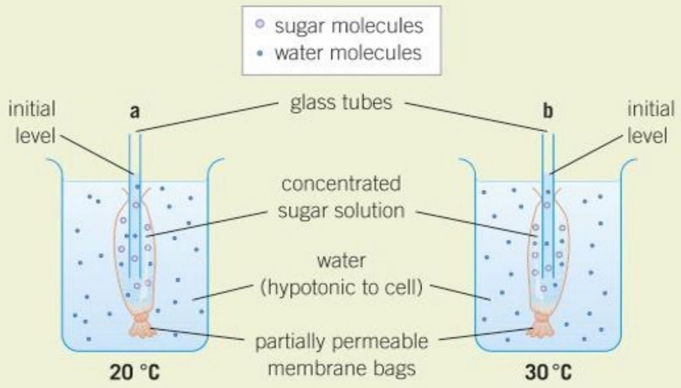


Figure 2

d Evaluate the use of these model cells in practical investigations to demonstrate the importance of osmosis in:

i animal cells [2 marks]

ii plant cells. [2 marks]

4 *Amoeba* is a single-celled animal that lives in ponds. It obtains oxygen for cell respiration from the water by diffusion across the cell membrane. Sticklebacks are small fish that live in the same habitat. They have a complicated structure of feathery gills to obtain oxygen. Water is pushed over the gills by muscular action.

a Explain why *Amoeba* can obtain sufficient oxygen for respiration by simple diffusion across its outer surface but the stickleback requires a special structure. [4 marks]

b Explain how the gills and the circulating blood will increase the diffusion of oxygen into the cells of the stickleback. [5 marks]

5 Exchanging materials with the outside world by diffusion is vital for most living organisms.

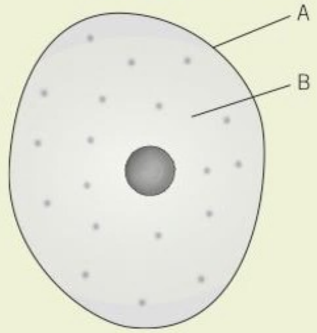
a Give **two** different adaptations that are found in living organisms to make this more efficient. [2 marks]

b For each adaptation in part **a**, explain how it makes the exchange process more efficient and give at least one example of where this adaptation is seen. [6 marks]

Practice questions

01 Figure 1 shows an animal cell.

Figure 1



01.1 What is structure **A**?
Choose the correct answer from the following options.

chloroplast	chromosome	nucleus	cell membrane

[1 mark]

01.2 What is structure **B**?
Choose the correct answer from the following options.

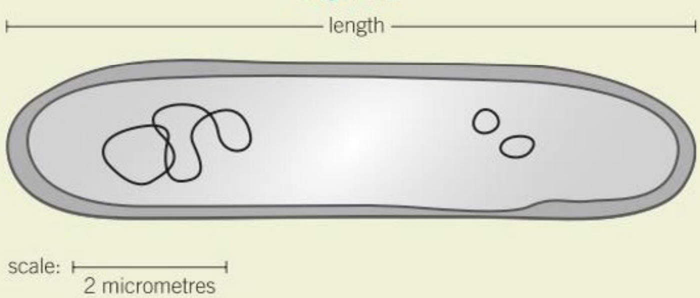
cell membrane	cytoplasm	ribosome	vacuole

[1 mark]

01.3 How can you tell that the cell in Figure 1 is an animal cell and not a plant cell?
Give one reason. [1 mark]

02 Figure 2 shows a drawing of a bacterial cell.

Figure 2



02.1 Use the scale to determine the length of the bacterial cell in micrometres. [1 mark]

02.2 A different bacterial cell has a real size of 6.4 micrometres.
Use the equation to work out the image size of this cell when magnified 600 times.
Give your answer in millimetres.

$$\text{magnification} = \frac{\text{size of image}}{\text{size of real object}}$$ [3 marks]

02.3 Bacterial cells are prokaryotic cells.
Describe **two** differences between a prokaryotic cell and a eukaryotic cell. [2 marks]

03.1 Describe the process by which water enters cells. [3 marks]

03.2 Figure 3 shows some equipment that can be used to determine the concentration of salt solution inside potato cells.

Figure 3

Describe how the equipment could be used to determine the concentration of salt solution inside potato cells.
You should include:

- variables that you would need to keep the same
- measurements you would need to take
- how you would conclude what the concentration of salt solution inside the potato cells is. [6 marks]

B 2 Cell division

2.1 Cell division

Learning objectives

After this topic, you should know:

- the role of the chromosomes in cells
- the importance of the cell cycle
- how cells divide by mitosis.

Figure 1 *This special image, a karyotype, shows the 23 pairs of chromosomes from a body cell of a female human being*

Synoptic link

For more information on genes look at Topics B13.5, B13.7, B13.8, and B13.9 and about DNA in Topic B13.4.

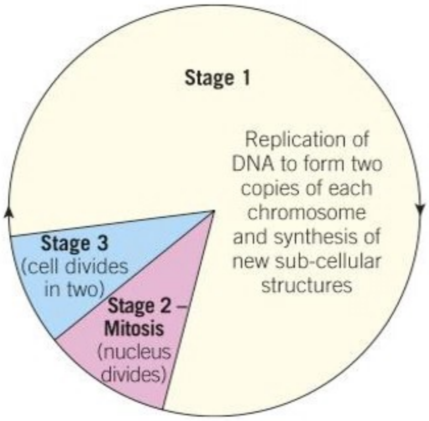


Figure 2 *The cell cycle. In rapidly growing tissue, stage 1 may only be a few hours, but in adult animals it can last for years*

New cells are needed for an organism, or part of an organism, to grow. They are also needed to replace cells that become worn out and to repair damaged tissue. However, the new cells must have the same genetic information as the originals so they can do the same job.

The information in the cells

Each of your cells has a nucleus that contains chromosomes. Chromosomes carry the genes that contain the instructions for making both new cells and all the tissues and organs needed to make an entire new you.

A gene is a small packet of information that controls a characteristic, or part of a characteristic, of your body. It is a section of DNA, the unique molecule that makes up your chromosomes.

Most of your characteristics are the result of many different genes rather than a single gene. The genes are grouped together on chromosomes. A chromosome may carry several hundred or even thousands of genes.

You have 46 chromosomes in the nucleus of your body cells. They are arranged in 23 pairs (see Figure 1). In each pair of chromosomes, one chromosome is inherited from the father and one from the mother. As such, sex cells (gametes) only have one chromosome from each pair, so only have 23 chromosomes in total.

The cell cycle and mitosis

Body cells divide in a series of stages known as the **cell cycle** (Figure 2). Cell division in the cell cycle involves a process called **mitosis** and it produces two identical cells. As a result, all your normal body cells have the same chromosomes and so the same genetic information. Cell division by mitosis produces the additional cells needed for growth and development in multicellular organisms, and for the replacement of worn out or damaged cells.

In asexual reproduction, the cells of the offspring are produced by mitosis from the cells of their parent. This is why they contain exactly the same genes as their parent with little or no genetic variation.

The cell cycle

The length of the cycle varies considerably. It can take less than 24 hours, or it can take several years, depending on the cells involved and the stage of life of the organism. The cell cycle is short as a baby develops before it is born, when new cells are being made all the time. It remains fairly rapid during childhood, but the cell cycle slows down once puberty is over and the body is adult. However, even in adults, there are regions where there is continued growth or a regular replacement of cells. They include the hair follicles, the skin, the blood, and the lining of the digestive system.

The cell cycle in normal, healthy cells follows a regular pattern (Figure 2):

- Stage 1: this is the longest stage in the cell cycle. The cells grow bigger, increase their mass, and carry out normal cell activities. Most importantly they replicate their DNA to form two copies of each chromosome ready for cell division. They also increase the number of sub-cellular structures such as mitochondria, ribosomes and chloroplasts ready for the cell to divide.
- Stage 2 – Mitosis: in this process one set of chromosomes is pulled to each end of the dividing cell and the nucleus divides.
- Stage 3: this is the stage during which the cytoplasm and the cell membranes also divide to form two identical daughter cells.

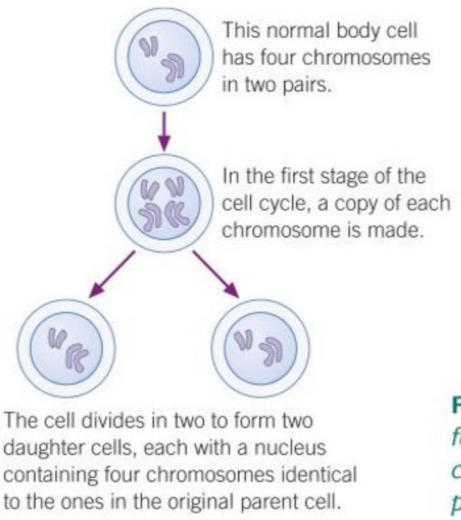


Figure 3 *Two identical cells are formed by mitotic division in the cell cycle. This cell is shown with only two pairs of chromosomes rather than 23*

In some parts of an animal or plant, mitotic cell division carries on rapidly all the time. For example, you constantly lose cells from the skin's surface and make new cells to replace them. In fact, about 300 million of your body cells die every minute, so cell division by mitosis is very important. In a child, mitotic divisions produce new cells faster than the old ones die. As an adult, cell death and mitosis keep more or less in balance. When you get very old, mitosis slows down and you show the typical signs of ageing.

1 Define the terms:
- **a** chromosome [1 mark]
- **b** gene [1 mark]
- **c** DNA. [1 mark]

2 Describe what happens during the three stages of the cell cycle. [6 marks]

3 **a** Explain why cell division by mitosis is so important in the body. [2 marks]

b Suggest why it is important for the chromosome number to stay the same when the cells divide to make other normal body cells. [3 marks]

Observing cell division

View a special preparation of a growing root tip under a microscope. When cells divide, the membrane round the nucleus disappears and the chromosomes take up stains, making them relatively easy to see. You should be able to see the chromosomes dividing to form two identical nuclei.

- Describe your observations of mitosis.

Study tip

Remember – cells produced when the nucleus divides by mitosis are genetically identical.

Key points

- In body cells, chromosomes are found in pairs.
- Body cells divide in a series of stages called the cell cycle.
- During the cell cycle the genetic material is doubled. It then divides into two identical nuclei in a process called mitosis.
- Before a cell can divide it needs to grow, replicate the DNA to form two copies of each chromosome and increase the number of sub-cellular structures. In mitosis one set of chromosomes is pulled to each end of the cell and the nucleus divides. Finally the cytoplasm and cell membranes divide to form two identical cells
- Mitotic cell division is important in the growth, repair, and development of multicellular organisms.

B2.2 Growth and differentiation

Learning objectives

After this topic, you should know:

- how cell differentiation varies in animals and plants
- the production and use of plant clones.

Figure 1 *This early embryo has only 8 cells – a lot of mitosis is needed before it becomes a teenager with around 3.7×10^{13} cells!*

At the moment of conception, a potential new human being is just one cell. By the time you are an adult, scientists have estimated that your body will contain around 37.2 trillion (3.72×10^{13}) cells – although estimates vary from 15 to 100 trillion! Almost all of these cells are the result of mitosis. The growth that takes place is amazing. Growth is a permanent increase in size as a result of cell division or cell enlargement (Figure 1).

The cells of your body, or any complex multicellular organism, are not all the same. They are not the same as the original cell either. This is because, as cells divide, grow and develop, they also begin to **differentiate**.

Differentiation in animal cells

In the early development of animal and plant embryos, the cells are unspecialised. Each one of them (known as a **stem cell**) can become any type of cell that is needed.

In animals, many types of cells become specialised very early in life. By the time a human baby is born, most of its cells are specialised to carry out a particular job, such as nerve cells, skin cells, or muscle cells. They have differentiated. Some of their genes have been switched on and others have been switched off. As a result, different types of specialised cells have different sub-cellular structures to carry out specific functions.

Most specialised cells can divide by mitosis, but they can only form the same sort of cell. Muscle cells divide to produce more muscle cells, for example. Some differentiated cells, such as red blood cells and skin cells, cannot divide at all and so **adult stem cells** replace dead or damaged cells. Nerve cells do not divide once they have differentiated and they are not replaced by stem cells. As a result, when nerve cells are damaged they are not usually replaced.

In a mature animal, little or no growth takes place. Cell division is almost entirely restricted to repair and replacement of damaged cells, and each differentiated cell type divides only to make more of the same cells.

Differentiation in plant cells

In contrast to animal cells, most plant cells are able to differentiate all through their lives. Undifferentiated cells are formed at active regions of the stems and roots, known as the meristems (Figure 2). In these areas, mitosis takes place almost continuously. The cells then elongate and grow before they finally differentiate.

Plants keep growing all through their lives at these 'growing points'. The plant cells produced do not differentiate until they are in their final position in the plant. Even then, the differentiation is not permanent. You can move a plant cell from one part of a plant to another. There it can redifferentiate and become a completely different type of cell. You cannot do that with animal cells – once a muscle cell, always a muscle cell.

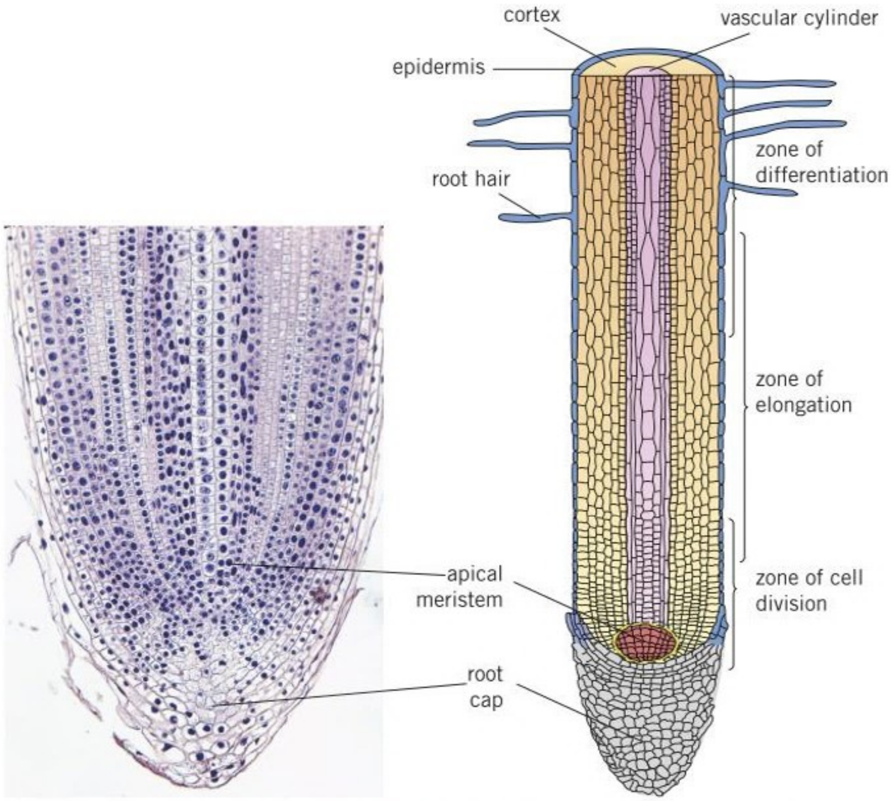


Figure 2 *The main zones of division, elongation, and differentiation in a plant root*

Cloning plants

Producing identical offspring is known as **cloning**. Huge numbers of identical plant clones can be produced from a tiny piece of leaf tissue. This is because, in the right conditions, a plant cell will become unspecialised and undergo mitosis many times. Each of these undifferentiated cells will produce more cells by mitosis. Given different conditions, these will then differentiate to form tissues such as xylem, phloem, photosynthetic cells, and root hair cells that are needed to form a tiny new plant. The new plant will be identical to the original parent.

It is difficult to clone animals because, as you have seen, most animal cells differentiate permanently early in embryo development. The cells cannot change back. As a result, artificial animal clones can only be made by cloning embryos in some way, although adult cells can be used to make an embryo.

1 **a** Define differentiation [1 mark]
b Describe why differentiation is important in living organisms. [2 marks]

2 Explain how differentiation differs in animal and plant cells. [4 marks]

3 Calculate by what order of magnitude an adult human is bigger than the original fertilised ovum (Topic B1.3). [4 marks]

4 Explain how the difference in differentiation patterns affects our ability to clone plants and animals. [6 marks]

Synoptic links

You learnt about some specialised cells that result from differentiation in Topic B1.4 and Topic B1.5.

You will learn more about the results of differentiation in Topic B3.1.

You will learn more about plant and animal cloning in Topic B14.5, and Topic B14.6.

Study tip

Cells produced by mitosis are genetically identical to the parent cell.

Key points

- In plant cells, mitosis takes place throughout life in the meristems found in the shoot and root tips.
- Many types of plants cells retain the ability to differentiate throughout life.
- Most types of animal cell differentiate at an early stage of development.

B2.3 Stem cells

Learning objectives

After this topic, you should know:

- how stem cells are different from other body cells
- the functions of stem cells in embryos, in adult animals, and in plants
- how treatment with stem cells may be used to treat people with different medical conditions.

Synoptic links

You will learn more about the spinal nerves in Topic B10.2, and about the eye in Topic B10.5.

You will learn more about insulin and the control of blood glucose levels in Topic B11.2 and Topic B11.3.

The function of stem cells

An egg and sperm cell fuse to form a **zygote**, a single new cell. That cell divides and becomes a hollow ball of cells – the embryo. The inner cells of this ball are the **embryonic stem cells** that differentiate to form all of the specialised cells of your body. Even when you are an adult, some of your stem cells remain. An adult stem cell is an undifferentiated cell of an organism that can give rise to many more cells of the same type. Certain other types of cell can also arise from stem cells by differentiation. Your bone marrow is a good source of **adult stem cells**. Scientists now think there may be a tiny number of stem cells in most of the different tissues in your body including your blood, brain, muscle, and liver.

Many of your differentiated cells can divide to replace themselves. However, some tissues cannot do this and stem cells can stay in these tissues for years, only needed if the cells are injured or affected by disease. Then they start dividing to replace the different types of damaged cell.

Using stem cells

Many people suffer and even die because parts of their body stop working properly. For example, spinal injuries can cause paralysis, because the spinal nerves cannot repair themselves. People with type 1 diabetes have to inject themselves with insulin every day because specialised cells in their pancreas do not work. Millions of people would benefit if we could replace damaged or diseased body parts.

In 1998, there was a breakthrough. Two scientists managed to culture human embryonic stem cells, capable of forming other types of cell. Scientists hope that the embryonic stem cells can be encouraged to grow into almost any different type of cell needed in the body. Already scientists have used nerve cells grown from embryonic stem cells to restore some movement to the legs of paralysed rats. In 2010, the first trials testing the safety of injecting nerve cells grown from embryonic stem cells into the spinal cords of paralysed human patients were carried out. The scientists and doctors hope it will not be long before they can use stem cells to help people who have been paralysed to walk again.

In 2014, doctors transplanted embryonic stem cells into the eyes of people going blind as a result of macular degeneration (Figure 1). It was a small study to check the safety of the technique but all of the patients found they could see better. Larger trials are now taking place. Scientists are also using different types of stem cells to try and grow cells that are sensitive to blood sugar levels and produce the hormone insulin to help treat people with diabetes.

Figure 1 *This is what the world looks like to someone with macular degeneration. The light-sensitive cells in the middle of their retina stop working. Soon stem cell therapy might be able to restore the lost vision*

We might also be able to grow whole new organs from embryonic stem cells. These could then be used in transplant surgery (Topic B2.4). Conditions from infertility to dementia could eventually be treated using stem cells.

Stem cells in plants

The stem cells from plant meristems can be used to make clones of the mature parent plant very quickly and economically. This is important as it gives us a way of producing large numbers of rare plants reliably and safely. We may be able to save some rare plants from extinction in this way. Plant cloning also gives us a way of producing large populations of identical plants for research. This is important as scientists can change variables and observe the effects on genetically identical individuals.

Cloning large numbers of identical plants from the stem cells in plant meristems is also widely used in horticulture producing large numbers of plants such as orchids for sale (Figure 2). In agriculture it is used to produce large numbers of identical crop plants with special features, such as disease resistance. For example, every banana you eat is produced by a cloned plant.

Figure 2 *Cloning exotic plants, like this orchid, from plant stem cells makes them relatively cheap and available for everyone to enjoy*

1 a Identify the differences between a stem cell and a normal body cell. [4 marks]
b Give three sources of stem cells. [3 marks]

2 Identify the advantages of using stem cells to treat diseases. [4 marks]

3 a Explain why the ability to clone large numbers of individual plants is such an advantage in plant research [3 marks]
b Suggest how it may enable us to save rare species of plants from extinction. [3 marks]

Synoptic links

You will learn more about cloning plants in Topic B14.5.

Go further

In 2016, Chinese scientists published papers showing how they had used embryonic stem cells to produce mouse sperm cells. They injected the sperm into mice eggs and produced live baby mice which went on to have babies of their own. Scientists hope stem cells may help overcome human infertility in the future.

Key points

- Embryonic stem cells (from human embryos) and adult stem cells (from adult bone marrow) can be cloned and made to differentiate into many different types of cell.
- Treatment with stem cells may be able to help conditions such as paralysis and diabetes.
- Stem cells from plant meristems are used to produce new plant clones quickly and economically for research, horticulture, and agriculture.

B2.4 Stem cell dilemmas

Learning objectives

After this topic, you should know:

- the process of therapeutic cloning
- some of the potential benefits, risks, and social and ethical issues of the use of stem cells in medical research and treatments.

As you saw in Topic B2.3, there are many potential benefits in using stem cells in human medicine and they are gradually being used to treat real patients. However, the technology is still very new so there are still practical risks as well as social and ethical issues raised by the use of stem cells in both medical research and in treatments.

Problems with embryonic stem cells

Many embryonic stem cells come from aborted embryos. Others come from spare embryos from fertility treatment, donated because they will not otherwise be used. Some people question the use of a potential human being as a source of cells, even to cure others. Some people feel that, as the embryo cannot give permission, using it is a violation of its human rights. The religious beliefs of others mean they cannot accept any interference with the process of human reproduction.

In addition, progress in developing therapies using embryonic stem cells has been relatively slow, difficult, expensive, and hard to control. However, it is easy to forget that scientists have only been working with them for around 20 years. The signals that control cell differentiation are still not completely understood. Not surprisingly it is proving difficult to persuade embryonic stem cells to differentiate into the type of cells needed to treat patients.

Figure 1 *Dream Alliance won the Welsh Grand National after revolutionary stem cell treatment on a badly damaged tendon. Doctors hope people will soon have the same benefits*

Embryonic stem cells divide and grow rapidly. This is partly why they are potentially so useful but there is some concern that embryonic stem cells might cause cancer if they are used to treat people. This has sometimes been a problem when they have been used to treat mice and in early human treatments for autoimmune diseases.

There is a risk that adult stem cells might be infected with viruses, and so could transfer the infections to patients. If stem cells from an adult are used to treat another unrelated person, they may trigger an immune response. The patient may need to take immunosuppressant drugs to stop their body rejecting the new cells. Scientists hope embryonic stem cells will solve this problem. The body of a mother does not reject the embryo, so they hope that embryonic stem cells will not be rejected by the patient.

Some people feel that a great deal of money and time is being wasted on stem cell research that would be better spent on research into other areas of medicine. Yet in spite of all these concerns, there is a lot of investment into stem cell research as many scientists and doctors are convinced stem cells have the potential to benefit many people.

The future of stem cell research

Scientists have found embryonic stem cells in the umbilical cord blood of newborn babies and even in the amniotic fluid that surrounds the fetus as it grows. Using these instead of cells from spare embryos may help to overcome some of the ethical concerns about their use.

Scientists are also finding ways of growing adult stem cells, although so far they have only managed to develop them into a limited range of cell types. Adult stem cells avoid the controversial use of embryonic tissue. They have been used successfully to treat some forms of heart disease and to grow some new organs such as tracheas (windpipes).

The area of stem cell research known as **therapeutic cloning** (Figure 2) has much potential but is proving very difficult. It involves using cells from an adult to produce a cloned early embryo of themselves. This would provide a source of perfectly matched embryonic stem cells. In theory, these could then be used for medical treatments such as growing new organs for the original donor. The new organs would not be rejected by the body because they have been made from the body's own cells and have the same genes.

Scientists have discovered stem cells in some of the tubes that connect the liver and the pancreas to the small intestine. They have managed to make these cells turn into the special insulin-producing cells in the pancreas that are so important for controlling blood sugar. These are the cells that are missing or destroyed in people with type 1 diabetes. Scientists have transplanted these modified stem cells into diabetic mice, which worked to control the blood sugar levels. The next stage is to work towards the same success in humans.

At the moment, after years of relatively slow progress, hopes are high again that stem cells will change the future of medicine. Currently, in the UK, stem cell research is being carried out into potential therapies to treat:

- spinal cord after injuries
- diabetes
- heart after damage in a heart attack
- eyesight in the blind
- damaged bone and cartilage.

It is not known how many of these hopes will be fulfilled – only time will tell.

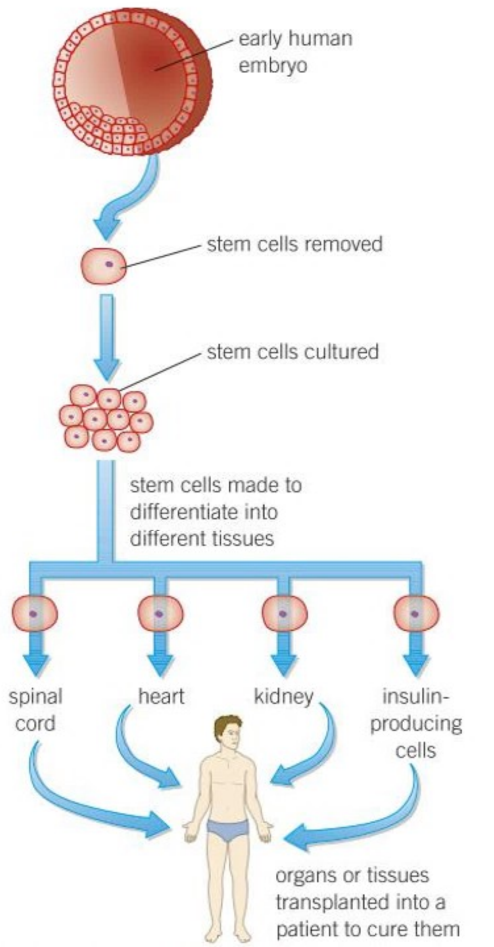


Figure 2 *This shows one way in which scientists hope embryonic stem cells might be formed into adult cells and used as human treatments in the future*

1 Give three examples where the use of stem cells could provide new treatments. [3 marks]

2 Explain the main arguments for and against the use of embryonic stem cells in medical research. [4 marks]

3 Explain how scientists are hoping to overcome the ethical objections to using embryonic stem cells in their research. [5 marks]

Key points

- Treatment with stem cells, from embryos or adult cell cloning, may be able to help with conditions such as diabetes.
- In therapeutic cloning, an embryo is produced with the same genes as the patient so the stem cells produced are not rejected and may be used for medical treatment.
- The use of stem cells has some potential risks and some people have ethical or religious objections.

B2 Cell division

Summary questions

1 **a** What is the cell cycle? [1 mark]

b Explain how and why you would expect the length of the cell cycle to vary:

i between an early embryo in the first days after fertilisation and a 5-year-old child [4 marks]

ii between a 13-year-old student and a 70-year-old adult. [5 marks]

2 **a** Explain what mitosis is and explain its role in the cell cycle. [3 marks]

b Explain, using diagrams, the stages of the cell cycle. [5 marks]

c The cell cycle is very important during the development of a baby from a fertilised egg. It is also important all through life. Explain why. [5 marks]

d The rate of the cell cycle can vary greatly.

i Which stage of the cell cycle is variable? [1 mark]

ii Explain when the cell cycle is likely to be very rapid in an human being, and when it is likely to be relatively slow. [5 marks]

3 **a** Describe what stem cells are. [2 marks]

b It is hoped that many different medical problems may be cured using stem cells. Explain how this might work. [4 marks]

c There are some ethical issues associated with the use of embryonic stem cells. Explain the arguments

i for and [4 marks]

ii against their use. [4 marks]

4 Plants have stem cells just as animals do.

a Where would you expect to find stem cells in a plant? [2 marks]

b Describe how plant stem cells differ from animal stem cells. [2 marks]

c Suggest two examples of the use of plant stem cells to produce plant clones. For each explain the advantages of using cloning from stem cells over normal plant reproduction. [6 marks]

5 In 2014, a paper in the journal *Cell Transplantation* reported on the case of a Polish man whose spinal cord had been severed in a stabbing, causing paralysis. He had been given a novel treatment – cells from the olfactory lobe of his brain (the area that analyses smells) were grown in culture and then injected around the site of the injury. Thin strips of nerves were attached between the two ends of the spinal cord to give a framework for recovery. He was given intensive physiotherapy. Over a period of months the patient began to recover some control of his legs. He also regained some control of his bladder, bowel, and sexual function. He can now walk with a frame.

a The cells he was given were not stem cells – they were cells that encourage the growth of nerve cells – but the research was supported and funded by groups involved in stem cell research. Suggest why stem cells might also be involved in this type of therapy in the future. [2 marks]

b The sight of a paralysed man walking, with difficulty, and the apparent regeneration of some of his spinal cord, caused a lot of excitement in the media. The scientists involved were very cautious but excited. Other scientists were very reluctant to see it as major progress. Evaluate this research from the information given here and indicate some of the problems still to be overcome before there is a useful cure for spinal injuries. [6 marks]

6 The racehorse Dream Alliance (Topic B2.4, Figure 1) won the 2009 Welsh Grand National after stem cell treatment for a badly injured tendon in his leg.

a Tendons do not heal easily. Explain how stem cells might help overcome such an injury. [3 marks]

b Horses and other animals have been having successful stem cell treatment for tendon injuries for around 10 years. People also suffer from tendon injuries but human trials are still in the relatively early stages. Suggest reasons why human treatments are so far behind those used by vets. [4 marks]

Practice questions

01.1 Which of the following structures is the **smallest**?

cell	chromosome	gene	nucleus

[1 mark]

01.2 Name the molecule that makes up chromosomes. [1 mark]

02 A body cell of a cat has 18 pairs of chromosomes that control characteristics, plus one pair of chromosomes that determines the sex of the cat. Body cells divide by a process called mitosis.

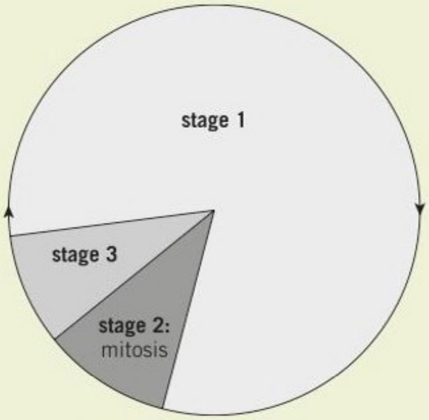
02.1 How many new daughter cells are formed when one of these cells divides by mitosis. [1 mark]

02.2 How many chromosomes each new cat cell will contain after mitosis. [1 mark]

02.3 Why is mitosis important to organisms? Give **two** reasons. [2 marks]

03 **Figure 1** shows a simplified diagram of the cell cycle.

Figure 1



H **03.1** The length of the cell cycle varies greatly between different types of cell.
In which of the following cells would the cycle be the shortest?

an adult brain cell	an embryonic cell
a teenager's kidney cell	an unfertilised egg cell

[1 mark]

03.2 Suggest a reason for your answer to **03.1**. [1 mark]

03.3 A student prepares a microscope slide with cells from a plant shoot and counts the number of cells he can see in the field of view. He calculates that 17% of the cells are in Stage 3 of the cell cycle.
If 3 cells are in Stage 3 of the cell cycle, calculate the total number of cells that the student can see. [2 marks]

H **03.4** Look at **Figure 1**.
Describe the changes that occur during each Stage of the cell cycle. [6 marks]

04 A scientist is studying a rare plant she found in the wild. She finds that when she cuts off a leaf, a new leaf will grow out of the stem.

04.1 Explain how a new leaf can grow even though there is no trace left of the original leaf. [2 marks]

04.2 Unlike the plant, most animals **cannot** grow back parts of their body after they have been cut off. Explain why this is. [2 marks]

04.3 The scientist wants more specimens of this rare plant for testing, but is unable to get hold of any others. Suggest one way in which the scientist could obtain more specimens. [1 mark]

05 Stem cells are undifferentiated cells. They divide to produce many identical cells from which other cells can develop by differentiation.

05.1 Name **one** part of the adult human body in which stem cells are relatively common. [1 mark]

05.2 Stem cells are used to treat some human diseases such as leukaemia. In the future, they may be used to help conditions such as diabetes and paralysis, but further research is required.
Therapeutic cloning is a technique in which embryonic stem cells are produced with the same DNA as the patient.
The nucleus is removed from a donated egg cell and replaced with the nucleus of a body cell from the patient. The cell is stimulated to divide and form a cloned embryo of the patient.
Stem cells are removed from the embryo and the embryo dies. These cells are cultured to form many embryonic stem cells, which can be stimulated to differentiate and form the required cells.
Explain the benefits and issues of using therapeutic cloning in medicine. [6 marks]

B 3 Organisation and the digestive system

3.1 Tissues and organs

Learning objectives

After this topic, you should know:

- how specialised cells become organised into tissues
- how several different tissues work together to form an organ.

As you have seen, cells are the basic building blocks of all living organisms. Unicellular and simple multicellular organisms carry out all the exchanges they need across their cell membranes. Large multicellular organisms may contain billions of cells and they have to overcome the problems linked to their size. They have evolved different ways of exchanging materials. During the development of a multicellular organism, cells **differentiate**, becoming specialised to carry out particular jobs. However, the adaptations of multicellular organisms go beyond specialised cells. Similar specialised cells are often found grouped together to form a tissue.

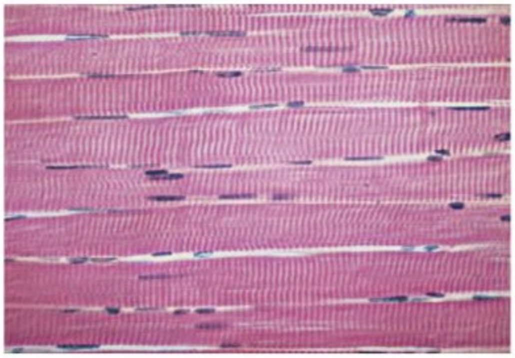


Figure 1 *Muscle tissue contracts to move your skeleton around – magnification × 4*

Synoptic links

For more information on specialised cells, look back at Topic B1.4 and Topic B1.5.

Tissues

A **tissue** is a group of cells with similar structure and function working together. For example, muscular tissue can contract to bring about movement (Figure 1). Glandular tissue contains secretory cells that can produce and release substances such as enzymes and hormones. Epithelial tissue covers the outside of your body as well as your internal organs.

Organs

Organs are collections of tissues. Each organ contains several tissues, all working together to perform a specific function. For example, the stomach, as shown in Figure 3, is an organ involved in the digestion of food. It contains:

- muscular tissue, to churn the food and digestive juices of the stomach together
- glandular tissue, to produce the digestive juices that break down food
- epithelial tissue, which covers the inside and the outside of the organ.

The pancreas is an organ that has two important functions. It makes hormones to control blood sugar, as well as some of the enzymes that digest food. It contains two very different types of tissue, which produce these different secretions (Figure 2).

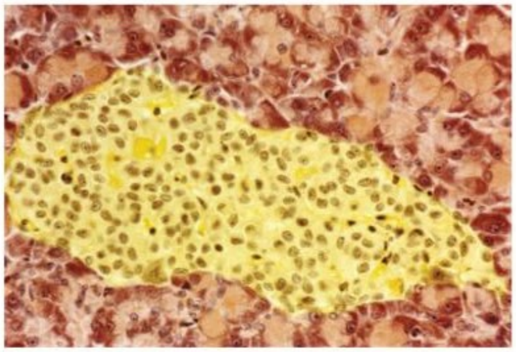


Figure 2 *The pancreas showing the tissue that makes hormones (stained yellow) and the tissue that makes enzymes (stained red) – magnification × 1250*

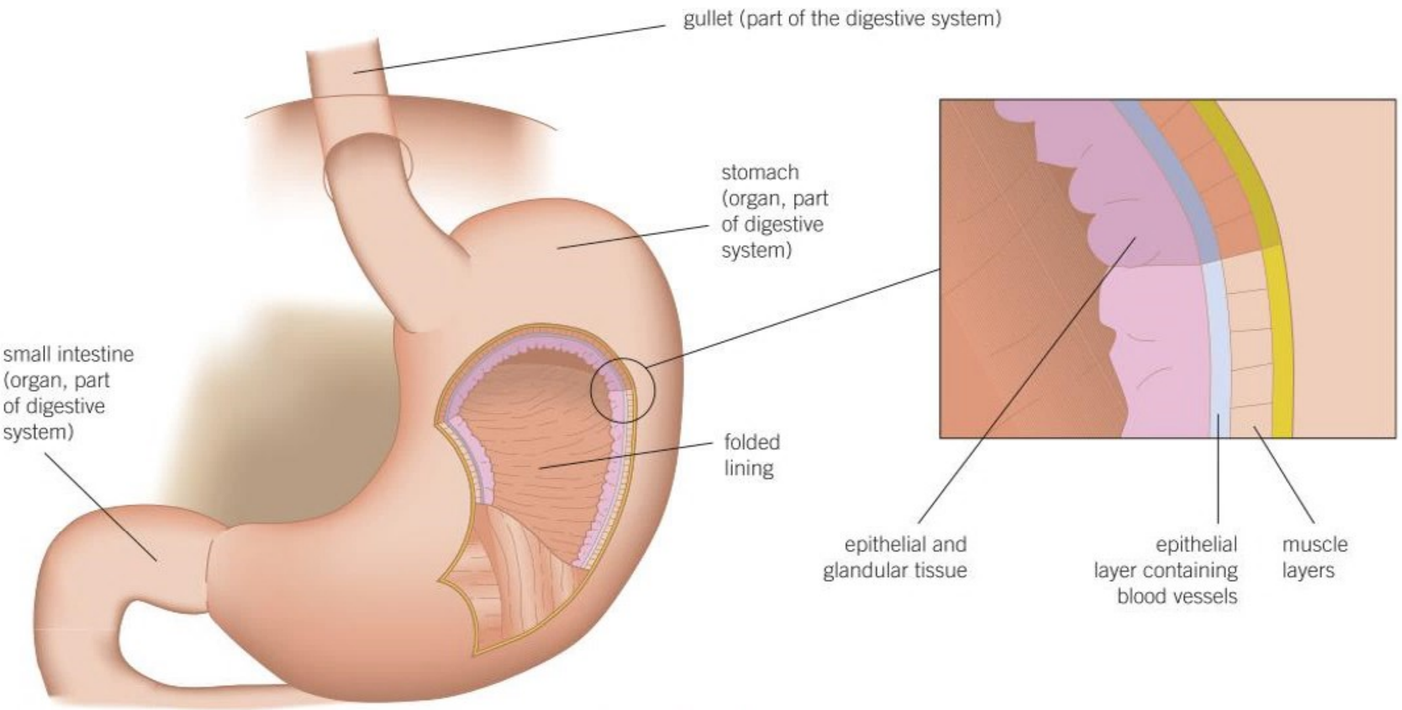


Figure 3 *The stomach contains several different tissues, each with a different function in the organ*

Organ systems

A whole multicellular organism is made up of a number of **organ systems** working together. Organ systems are groups of organs that all work together to perform specific functions. The way in which one organ functions often depends on other organs in the system. Organ systems work together to form organisms. Organ systems in the human body include the digestive system, the circulatory system, and the gas exchange system. All of these systems have adaptations in some of their organs that make them effective as exchange surfaces. These adaptations include features to increase the surface area of part of an organ system, a rich blood supply to areas where exchange takes place, areas with short diffusion distances for exchange, and mechanisms to increase the concentration gradients by ventilating surfaces or moving materials on.

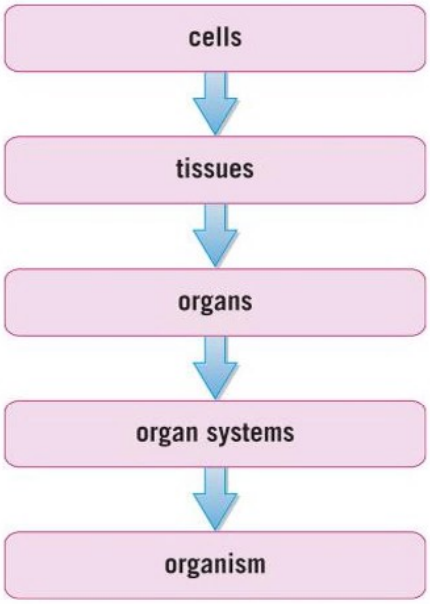


Figure 4 *Larger multicellular organisms have many levels of organisation*

1 a Define the word tissue. [1 mark]
b Define the word organ. [1 mark]

2 For each of the following, identify whether they are a specialised cell, a tissue, or an organ. Explain your answers.
a sperm [2 marks]
b kidney [2 marks]
c stomach [2 marks]

3 Describe how the stomach is adapted for its role in the digestion of food. [5 marks]

Key points

- A tissue is a group of cells with similar structure and function.
- Organs are collections of tissues performing specific functions.
- Organs are organised into organ systems, which work together to form organisms.

B3.2 The human digestive system

Learning objectives

After this topic, you should know:

- the position of the main organs of the human digestive system.

Study tip

Learn the names of the parts of the digestive system. Make sure you know the difference between the larger, lobed liver and the thinner leaf-like pancreas.

The digestive system

Your digestive system is between 6 and 9 m long – 9 million times or 6 orders of magnitude longer than an average human cell! The digestive system of humans and other mammals exchanges substances with the environment. The food you take in and eat is made up of large insoluble molecules. Your body cannot absorb and use these molecules. They need to be broken down or digested to form smaller, soluble molecules that can then be absorbed and used by your cells. This process of digestion takes place in your **digestive system**, one of the major organ systems of the body.

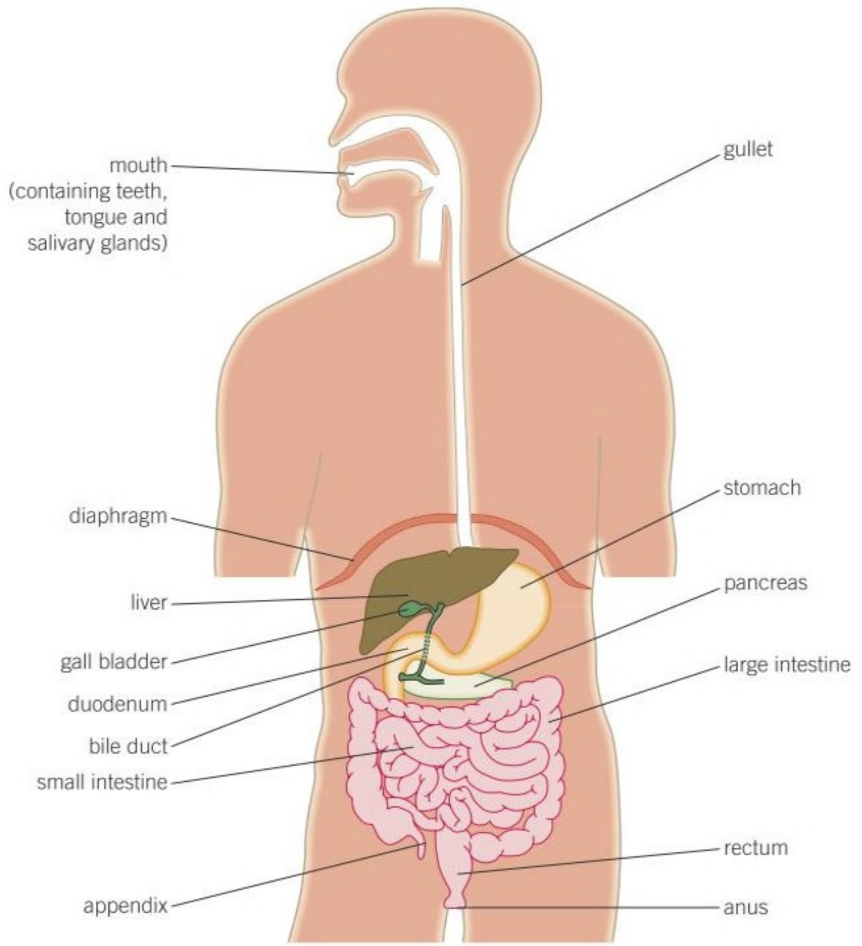


Figure 1 *The main organs of the human digestive system*

The digestive system is a muscular tube that squeezes your food through it. It starts at one end with your mouth, and finishes at the other with your anus. The digestive system contains many different organs. There are glands such as the pancreas and salivary glands. These glands make and release digestive juices containing **enzymes** to break down your food.

The stomach and the small intestine are the main organs where food is digested. Enzymes break down the large insoluble food molecules into smaller, soluble ones. Your small intestine is also where the soluble food molecules are absorbed into your blood. Once there, they get transported in the bloodstream around your body. The small intestine is adapted to have a very large surface area as it is covered in villi. It also has a good blood supply and short diffusion distances to the blood vessels. This greatly increases diffusion and active transport from the small intestine to the blood.

Synoptic links

You can remind yourself about the adaptations of the villi in the small intestine as an exchange surface in Topic B1.10.

Figure 2 *The large surface area of the villi of the small intestine helps make it possible to absorb the digested food molecules from the gut into the blood – magnification × 70*

The muscular walls of the small intestine squeeze the undigested food onwards into your large intestine. This is where water is absorbed from the undigested food into your blood. The material left forms the faeces. Faeces are stored and then pass out of your body through the rectum and anus back into the environment.

Other organs associated with the digestive system include the liver. The liver is a large organ that carries out many different functions in your body. The function of the liver that is most closely linked to the digestive system is the production of bile, which helps in the digestion of lipids.

1 Match each of the following organs to its correct function.

A	Liver	**1**	Breaking down large insoluble molecules into smaller soluble molecules and absorption
B	Stomach	**2**	Absorbing water from undigested food
C	Small intestine	**3**	Producing bile
D	Large intestine	**4**	Breaking down large insoluble molecules into smaller soluble molecules

[4 marks]

2 Explain the difference between organs and organ systems, giving two examples. [4 marks]

3 Using the human digestive system as an example, explain how the organs in an organ system rely on each other to function properly. [6 marks]

Key points

- Organ systems are groups of organs that perform specific functions in the body.
- The digestive system in a mammal is an organ system where several organs work together to digest and absorb food.

B3.3 The chemistry of food

Learning objectives

After this topic, you should know:

- the basic structures of carbohydrates, proteins, and lipids.

Carbohydrates, lipids, and proteins are the main compounds that make up the structure of a cell. They are vital components in the balanced diet of any organism that cannot make its own food. Carbohydrates, lipids, and proteins are all large molecules that are often made up by smaller molecules joined together as part of the cell metabolism.

Carbohydrates

Carbohydrates provide us with the fuel that makes all of the other reactions of life possible. They contain the chemical elements carbon, hydrogen, and oxygen.

All carbohydrates are made up of units of sugars.

- Some carbohydrates contain only one sugar unit. The best known of these single sugars is glucose, $C_6H_{12}O_6$. Other carbohydrates are made up of two sugar units joined together, for example sucrose, the compound we call 'sugar' in everyday life. These small carbohydrate units are referred to as **simple sugars**.
- Complex carbohydrates such as starch and cellulose are made up of long chains of simple sugar units bonded together (Figure 1).

Carbohydrate-rich foods include bread, potatoes, rice, and pasta. Most of the carbohydrates you eat will be broken down to glucose used in cellular respiration to provide energy for metabolic reactions in your cells. The carbohydrate cellulose is an important support material in plants.

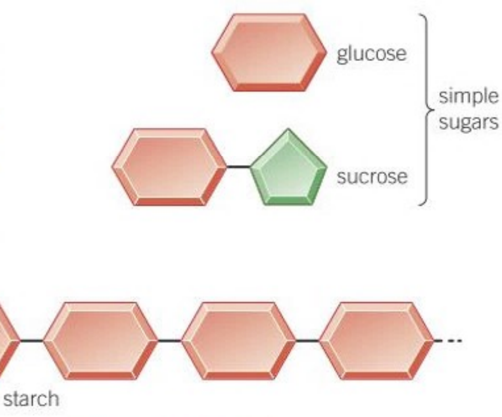


Figure 1 *Carbohydrates are all based on simple sugar units*

Lipids

Lipids are fats (solids) and oils (liquids). They are the most efficient energy store in your body and an important source of energy in your diet. Combined with other molecules, lipids are very important in your cell membranes, as hormones, and in your nervous system. Like carbohydrates, lipids are made up of carbon, hydrogen, and oxygen. All lipids are insoluble in water.

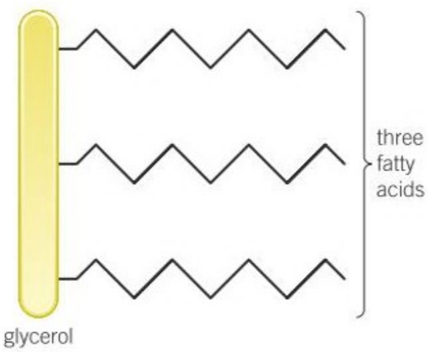


Figure 2 *Lipids are made of three molecules of fatty acids joined to a molecule of glycerol*

Lipids are made up of three molecules of **fatty acids** joined to a molecule of **glycerol** (Figure 2). The glycerol is always the same, but the fatty acids vary. Lipid-rich food includes all the oils, such as olive oil and corn oil, as well as butter, margarine, cheese, and cream. The different combination of fatty acids affects whether the lipid will be a liquid oil or a solid fat.

Proteins

Proteins are used for building up the cells and tissues of your body, as well as the basis of all your enzymes. Between 15 and 16% of your body mass is protein. Protein is found in tissues ranging from your hair and nails to the muscles that move you around and the enzymes that control your body chemistry. Proteins are made up of the elements carbon, hydrogen, oxygen, and nitrogen. Protein-rich foods include meat, fish, pulses, and cheese.

A protein molecule is made up of long chains of small units called **amino acids** (Figure 3). There are around 20 different amino acids, and they are joined together into long chains by special bonds. Different arrangements of the various amino acids give you different proteins.

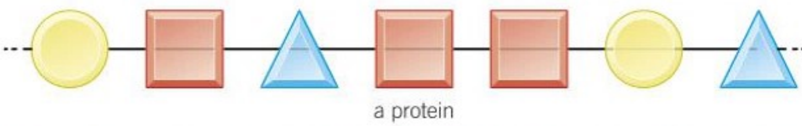


Figure 3 *Amino acids are the building blocks of proteins. They can join in an almost endless variety of ways to produce different proteins*

The long chains of amino acids that make up a protein are folded, coiled, and twisted to make specific 3D shapes. It is these specific shapes that enable other molecules to fit into the protein. The bonds that hold the proteins in these 3D shapes are very sensitive to temperature and pH, and can easily be broken. If this happens, the shape of the protein is lost and it may not function any more in your cells. The protein is **denatured**.

Proteins carry out many different functions in your body. They act as:

- structural components of tissues such as muscles and tendons
- hormones such as insulin
- antibodies, which destroy pathogens and are part of the immune system
- enzymes, which act as catalysts.

1 **a** Explain what a protein is. [1 mark]
b State how proteins are used in the body. [4 marks]

2 Describe the main similarities and differences between the three main groups of chemicals (carbohydrates, proteins, and lipids) in the body. [6 marks]

3 Describe how you would test a food sample to see if it contained:
a starch [2 marks]
b lipids. [2 marks]

4 Explain why lipids can be either fats or oils. [3 marks]

5 Explain how simple sugars are related to complex carbohydrates. [3 marks]

Food tests

You can identify the main food groups using standard food tests.

- Carbohydrates:
  - iodine test for starch – yellow-red iodine solution turns blue-black if starch is present.
  - Benedict's test for sugars – blue Benedict's solution turns brick red on heating if a sugar such as glucose is present.
- Protein: Biuret test – blue Biuret reagent turns purple if protein is present.
- Lipids: ethanol test – ethanol added to a solution gives a cloudy white layer if a lipid is present. Ethanol is highly flammable and harmful.

Safety: Biuret solution is corrosive. Wear chemical and splash-proof eye protection.

Key points

- Carbohydrates are made up of units of sugar.
- Simple sugars are carbohydrates that contain only one or two sugar units – they turn blue Benedict's solution brick red on heating.
- Complex carbohydrates contain long chains of simple sugar units bonded together. Starch turns yellow-red iodine solution blue-black.
- Lipids consist of three molecules of fatty acids bonded to a molecule of glycerol. The ethanol test indicates the presence of lipids in solutions.
- Protein molecules are made up of long chains of amino acids. Biuret reagent turns from blue to purple in the presence of proteins.

B3.4 Catalysts and enzymes

Learning objectives

After this topic, you should know:

- what a catalyst is
- how enzymes work as biological catalysts
- what the metabolism of the body involves.

In everyday life, you control the rate of chemical reactions all the time. You increase the temperature of your oven to speed up chemical reactions when you cook, and you cool food down in the fridge to slow down the reactions that cause food to go off.

Sometimes people use special chemicals known as **catalysts** to speed up reactions. A catalyst speeds up a chemical reaction, but it is not used up in the reaction. You can use a catalyst over and over again.

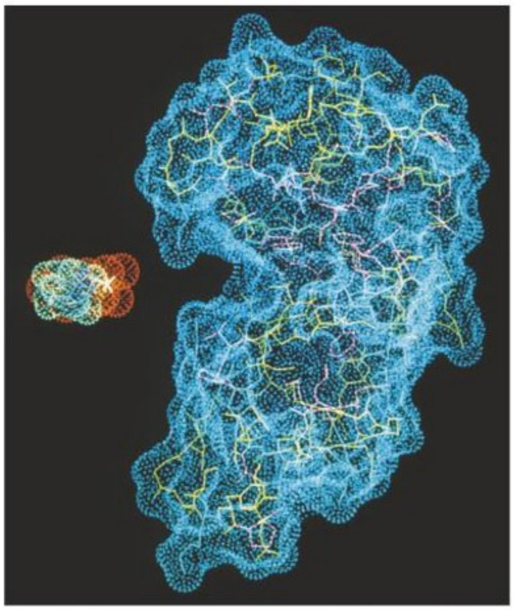


Figure 1 *Enzymes are made up of chains of amino acids folded together to make large complex molecules, as you can see in this computer-generated image*

Enzymes – biological catalysts

In your body, the rate of chemical reactions is controlled by enzymes. These are special biological catalysts that speed up reactions. Each enzyme interacts with a particular substrate (reactant).

Enzymes are large protein molecules. The shape of an enzyme is vital for the enzyme to function. The long chains of amino acids are folded to produce a molecule with an **active site** that has a unique shape so it can bind to a specific substrate molecule.

How do enzymes work?

The lock and key theory is a simple model of how enzymes work. The substrate of the reaction to be catalysed fits into the active site of the enzyme. You can think of it like a lock and key. Once it is in place, the enzyme and the substrate bind together. The reaction then takes place rapidly and the products are released from the surface of the enzyme (Figure 2). Remember that enzymes can join small molecules together as well as break up large ones. There are other, more complex models of how enzymes work but they are all based on the lock and key theory.

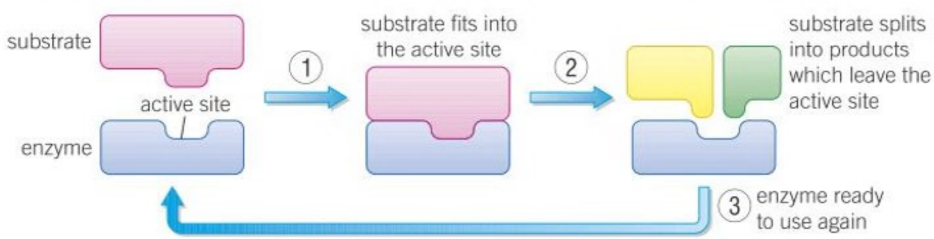


Figure 2 *Enzymes act as catalysts using the 'lock and key' mechanism shown here*

Metabolic reactions

Enzymes do not change a reaction in any way, they just make it happen faster. Enzymes control the **metabolism** – that is the sum of all the reactions in a cell or in the body. Different enzymes catalyse (speed up) specific types of metabolic reactions:

- Building large molecules from lots of smaller ones. This includes building starch, glycogen or cellulose from glucose; lipids from fatty acids; or proteins from amino acids. Plant cells also combine carbon dioxide and water to make glucose, and use glucose and nitrate ions to make amino acids.

Study tip

Remember that it is the shape of the active site of the enzyme that allows it to bind with the substrate.

- Changing one molecule into another. This includes changing one simple sugar into another, such as glucose to fructose, and converting one amino acid into another.
- Breaking down large molecules into smaller ones. This includes breaking down carbohydrates, lipids, and proteins into their constituent molecules during digestion; breaking down glucose in cellular respiration; and breaking down excess amino acids to form urea, and other molecules that can be used in respiration.

Each of your cells can have a hundred or more chemical reactions going on within it at any one time. Each of the different types of reaction is controlled by a different specific enzyme. Enzymes deliver the control that makes it possible for your cell chemistry to work without one reaction interfering with another.

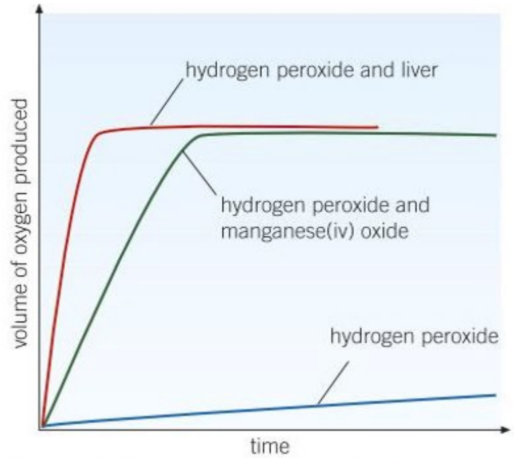


Figure 3 *The decomposition of hydrogen peroxide to oxygen and water happens much faster using a catalyst. The reaction takes place faster when catalysed by enzymes (found in liver) than when catalysed by manganese(IV) oxide*

Breaking down hydrogen peroxide

You can investigate the impact of both an inorganic catalyst and an enzyme on the breakdown of dilute hydrogen peroxide solution into oxygen and water using:

a manganese(IV) oxide (an inorganic catalyst) and

b raw liver or potato (which contain the enzyme catalase).

Hydrogen peroxide is a poisonous compound that is often a waste product of reactions in cells. It breaks down slowly itself but it is important that it gets broken down into harmless oxygen and water quickly, before it causes any damage.

You can determine the rate of the reaction by measuring the volume of oxygen produced over time. A simple way to do a quick comparison between the inorganic catalyst and the enzyme is to add a drop of washing-up liquid to the hydrogen peroxide. Add the inorganic catalyst or the enzyme (the liver or potato) and measure how quickly the foam produced by the bubbles of gas rises up the test tube!

- Describe your observations and interpret the graph (Figure 3).

Safety: Wear eye protection. 20 vol hydrogen peroxide – irritant. Manganese(IV) oxide – harmful.

1 Define each of the following terms:
   a a catalyst [1 mark]
   b an enzyme [1 mark]
   c the active site of an enzyme. [1 mark]

2 **a** Describe what enzymes are made of. [1 mark]
   b Explain in detail how enzymes act to speed up reactions in your body. [5 marks]

3 **a** Give three clear examples of the type of reactions that are catalysed by enzymes. [3 marks]
   b Explain how enzymes are important in the metabolism of a cell or organism. [6 marks]

Key points

- Catalysts increase the rate of chemical reactions without changing chemically themselves.
- Enzymes are biological catalysts and catalyse specific reactions in living organisms due to the shape of their active site. This is the lock and key theory of enzyme action.
- Enzymes are proteins. The amino acid chains are folded to form the active site, which matches the shape of a specific substrate molecule.
- The substrate binds to the active site and the reaction is catalysed by the enzyme.
- Metabolism is the sum of all the reactions in a cell or the body.

B3.5 Factors affecting enzyme action

Learning objectives

After this topic, you should know:

- how temperature and pH affect enzyme action
- different enzymes work fastest at different temperatures and pH values.

A container of milk left at the back of your fridge for a week or two will be disgusting. The milk will go off as enzymes in bacteria break down the protein structure. Leave your milk in the sun for a day and the same thing happens – but much faster. Temperature affects the rate at which chemical reactions take place, even when they are controlled by biological catalysts.

Biological reactions are affected by the same factors as any other chemical reactions. These factors include concentration, temperature, and surface area. However, in living organisms, an increase in temperature only increases the rate of reaction up to a certain point.

The effect of temperature on enzyme action

The reactions that take place in cells happen at relatively low temperatures. As with other reactions, the rate of enzyme-controlled reactions increases as the temperature increases.

However, for most organisms this is only true up to temperatures of about 40 °C. After this, the protein structure of the enzyme is affected by the high temperature. The long amino acid chains begin to unravel, and as a result, the shape of the active site changes. The substrate will no longer fit in the active site. The enzyme is said to have been **denatured**. It can no longer act as a catalyst, so the rate of the reaction drops dramatically. Most human enzymes work best at 37 °C, which is human body temperature.

Without enzymes, none of the reactions in your body would happen fast enough to keep you alive. This is why it is dangerous if your temperature goes too high when you are ill. Once your body temperature reaches about 41 °C, your enzymes start to be denatured, which will result in death.

Go further

Extremophiles are organisms that live in the most extreme environments. Many extremophiles are prokaryotes, and their enzymes have chemical adaptations enabling them to function in extremes of saltiness, high temperature, and cold. We use enzymes from extremophile bacteria that live in hot springs in the polymerase chain reaction (PCR). PCR is a key process in DNA fingerprinting and genome analysis.

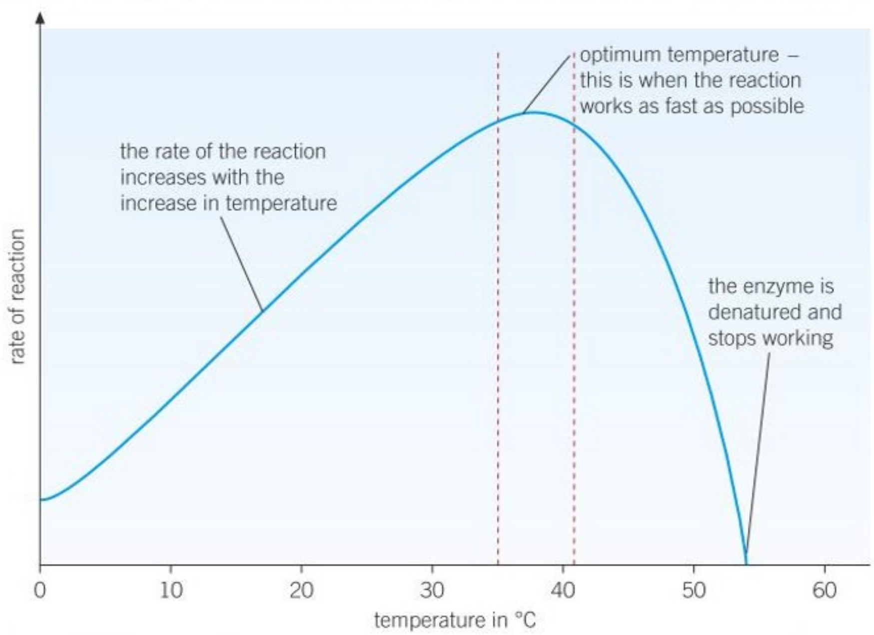


Figure 1 *The rate of an enzyme-controlled reaction increases as the temperature rises – but only until the protein structure of the enzyme breaks down*

Figure 2 *In an extreme environment, such as the hot springs found in Iceland, it is amazing that any enzymes function at all*

Not all enzymes work best at around 40 °C. Bacteria living in hot springs survive at temperatures up to 80 °C and higher (Figure 2). On the other hand, some bacteria that live in the very cold, deep seas have enzymes that work effectively at 0 °C and below.

Effect of pH on enzyme action

The shape of the active site of an enzyme comes from forces between the different parts of the protein molecule. These forces hold the folded chains in place. A change in pH affects these forces. That's why it changes the shape of the molecule. As a result, the specific shape of the active site is lost, so the enzyme no longer acts as a catalyst. Different enzymes work best at different pH levels. A change in pH can stop them working completely. You will learn more about digestive enzymes and pH ranges in Topic B3.6.

Plotting graphs

Drawing graphs

When you investigate the effect of different conditions on the rate of enzyme controlled reactions you will often need to plot a graph of your results.

- Choose your scale carefully – look at the size of your graph paper and the range of your results before deciding on your scale.
- Label your *x* and *y* axes carefully.
- Make sure you show the units on your labelled axes.
- Plot each point as accurately as possible.
- Draw the line of best fit through your points. Don't worry if all your points don't fit on the line. Practice drawing a line of best fit a few times, but make sure your line of best fit is only ever one clear line.
- You can use a graph to calculate the rate of your enzyme controlled reaction. Plot a line graph of some change in the reaction mixture over time. The rate of reaction at any given time is found by calculating the gradient of the tangent drawn at that point on the line.

You can find more about drawing graphs in the Maths skills Topics M4c and M4d.

1 Describe the effect of temperature on an enzyme-controlled reaction. Use Figure 1 to help you. [3 marks]

2 Explain the effect of temperature and pH on enzyme action. [4 marks]

3 When you get an infectious disease you may 'get a temperature'. This is a way your body defends you as many microorganisms cannot reproduce at high temperatures. However, people always try to bring the temperature of an ill person down. Explain why this may be the case. [4 marks]

Study tip

Enzymes aren't killed (they are molecules, not living things themselves) – so make sure that you use the term denatured.

Key points

- Enzyme activity is affected by temperature and pH.
- High temperatures denature the enzyme, changing the shape of the active site.
- pH can affect the shape of the active site of an enzyme and make it work very efficiently or stop it working.

B3.6 How the digestive system works

Learning objectives

After this topic, you should know:

- how the food you eat is digested in your body
- the roles played by the different digestive enzymes.

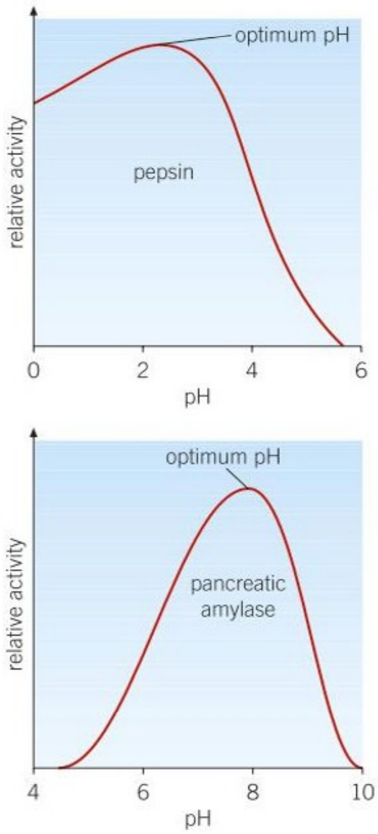


Figure 1 *These two digestive enzymes need very different pH levels to work at their maximum rate. Pepsin is found in the stomach, along with hydrochloric acid, while pancreatic amylase is in the first part of the small intestine along with alkaline bile*

Synoptic links

For more information on moving substances in and out of cells, see Topic B1.6, Topic B1.7, Topic B1.8, and Topic B1.9, and on adaptations for effective absorption, see Topic B1.10.

The food you take in and eat is made up of large insoluble molecules, including starch (a carbohydrate), proteins, and fats. Your body cannot absorb and use these molecules, so they need to be broken down or digested to form smaller, soluble molecules. These can then be absorbed in your small intestine and used by your cells. It is this chemical breakdown of your food that is controlled by the digestive enzymes in your digestive system.

Digestive enzymes

Most of your enzymes work *inside* the cells of your body, controlling the rate of the chemical reactions. Your digestive enzymes are different. They work *outside* your cells. They are produced by specialised cells in glands (such as your salivary glands and your pancreas), and in the lining of your digestive system. The enzymes then pass out of these cells into the digestive system itself, where they come into contact with food molecules.

Your digestive system is a hollow, muscular tube that squeezes your food. It helps to break up your food into small pieces that have a large surface area for your enzymes to work on. It mixes your food with your digestive juices so that the enzymes come into contact with as much of the food as possible. The muscles of the digestive system move your food along from one area to the next. Different areas of the digestive system have different pH levels which allow the enzymes in that region to work as efficiently as possible. For example, the mouth and small intestine are slightly alkaline, while the stomach has a low, acidic pH value.

Digesting carbohydrates

Enzymes that break down carbohydrates are called **carbohydrases**. Starch is one of the most common carbohydrates that you eat. It is broken down into sugars in your mouth and small intestine. This reaction is catalysed by an enzyme called **amylase**.

Amylase is produced in your salivary glands, so the digestion of starch starts in your mouth. Amylase is also made in the pancreas. No digestion takes place inside the pancreas. All the enzymes made there flow into your small intestine, where most of the starch you eat is digested.

Digesting proteins

The breakdown of protein foods such as meat, fish, and cheese into amino acids is catalysed by protease enzymes. **Proteases** are produced by your stomach, your pancreas, and your small intestine. The breakdown of proteins into **amino acids** takes place in your stomach and small intestine.

Digesting fats

The lipids (fats and oils) that you eat are broken down into **fatty acids** and **glycerol** in the small intestine. The reaction is catalysed by **lipase** enzymes, which are made in your pancreas and your small intestine. Again, the enzymes made in the pancreas are passed into the small intestine.

Once your food molecules have been completely digested into soluble glucose, amino acids, fatty acids, and glycerol, they leave your small intestine. They pass into your bloodstream to be carried around the body to the cells that need them.

Discovering the roles of the different areas of the digestive system hasn't been easy. For example, when Alexis St Martin suffered a terrible gunshot wound in 1822, Dr William Beaumont managed to save his life. However, Alexis was left with a hole (or fistula) from his stomach to the outside world. Dr Beaumont then used this hole to find out what happened in Alexis's stomach as he digested food!

The effect of pH on the rate of reaction of amylase

Investigating the effect of different pH on the rate of reaction of amylase helps show why the varying pH of the digestive system is so important.

Steps in this investigation include:

- Placing several different starch solutions of a known volume and concentration in a water bath not higher than 37 °C
- Adding a buffer solution at a different pH to each starch solution
- Setting up spotting tiles for each test solution with a drop of iodine in each well
- Mixing the same volume and concentration of amylase into each tube
- Starting a stop-clock as soon as the enzyme is added.
- Taking samples every 30 seconds using a pipette and adding each sample to an iodine-filled well.
- Observing and recording results that can be displayed graphically to compare the effect of pH on the rate of an amylase-catalysed reaction.

1 Explain why amylase, starch, and iodine are used in this investigation.
2 Explain why is it important that the concentration and volume of all the test starch solutions and the enzyme added are known and are the same.
3 Explain why all the test solutions are kept in a water bath at the same temperature and why that temperature must be controlled below 37 °C.
4 Explain the purpose of the spotting tiles with iodine in the wells.
5 The pipettes used to take samples must be rinsed out with clean water between each sample. Suggest a reason for this.
6 If all the starch is broken down before the first sampling, or if no starch was broken down after an hour, it would be hard to get useful results. Suggest reasons for both of these situations and ways of overcoming the difficulties.

Key points

- Digestion involves the breakdown of large insoluble molecules into soluble substances that can be absorbed into the blood across the wall of the small intestine.
- Digestive enzymes are produced by specialised cells in glands and in the lining of the digestive system.
- Carbohydrases such as amylase catalyse the breakdown of carbohydrates to simple sugars.
- Proteases catalyse the breakdown of proteins to amino acids.
- Lipases catalyse the breakdown of lipids to fatty acids and glycerol.

1 Three types of enzymes found in the body are called amylase, protease, and lipase.
 a Describe where each enzyme is made in the body. [3 marks]
 b Identify which reaction each enzyme catalyses. [3 marks]
 c Describe where each reaction works in the digestive system. [3 marks]
2 Look at Figure 1.
 a At which pH does pepsin work best? [1 mark]
 b At which pH does pancreatic amylase work best? [1 mark]
 c What happens to the activity of the enzymes as pH increases? [2 marks]
 d Explain why this change in activity happens. [4 marks]
3 Explain the importance of the digestion of food in terms of the molecules involved and the role of enzymes in the gut. [6 marks]

B3.7 Making digestion efficient

Learning objectives

After this topic, you should know:

- the roles of hydrochloric acid and bile in making digestion more efficient.

Your digestive system produces many enzymes that speed up the breakdown of the food you eat. As your body is kept at a fairly steady 37 °C, your enzymes have an optimum temperature that allows them to work as fast as possible.

Keeping the pH in your digestive system at optimum levels isn't that easy, because different enzymes work best at different pH levels. For example, the protease enzyme found in your stomach works best in acidic conditions, while the proteases made in your pancreas need alkaline conditions to work at their best. So, your body makes a variety of different chemicals that help to keep conditions ideal for your enzymes all the way through your digestive system.

Breaking down protein

You can see the effect of acid on pepsin (the protease found in the stomach), quite simply. Set up three test tubes: one containing pepsin, one containing hydrochloric acid, and one containing a mixture of the two. Keep them at body temperature in a water bath. Add a similar-sized chunk of meat to all three of them. Set up a webcam and watch for a few hours to see what happens.

- What conclusions can you make?

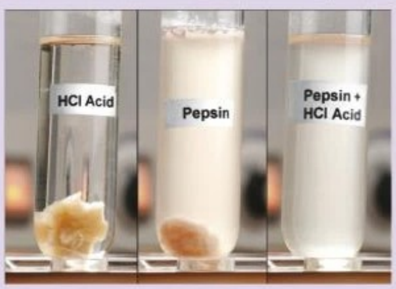


Figure 1 *These test tubes show clearly the importance of protein-digesting enzymes and hydrochloric acid in your stomach. Meat was added to each tube at the same time*

Safety: Wear eye protection.

Changing pH in the digestive system

You have around 35 million glands in the lining of your stomach. These secrete pepsin, a protease enzyme, to digest the protein you eat. Pepsin works best in an acidic pH. Your stomach also produces a relatively concentrated solution of hydrochloric acid from the same glands. In fact, your stomach produces around 3 litres of hydrochloric acid a day! This acid allows your stomach protease enzymes to work very effectively. It also kills most of the bacteria that you take in with your food.

Your stomach also produces a thick layer of mucus. This coats your stomach walls and protects them from being digested by the acid and the enzymes. If someone develops a stomach ulcer, the protecting mucus is lost and acid production may increase. The lining of the stomach is then attacked by the acid and the protein-digesting enzymes, which can be very painful.

After eating a meal, a few hours later – depending on the size and type of the meal – your food leaves your stomach. It moves on into your small intestine. Some of the enzymes that catalyse digestion in your small intestine are made in your pancreas. Some are also made in the small intestine itself. They all work best in an alkaline environment.

The acidic liquid coming from your stomach needs to become an alkaline mixture in your small intestine. So this can happen, your liver makes a green-yellow alkaline liquid called **bile**. Bile is stored in your gall bladder until it is needed.

As food comes into the small intestine from the stomach, bile is squirted onto it through the bile duct. The bile neutralises the acid that was added to the food in the stomach. This provides the alkaline conditions necessary for the enzymes in the small intestine to work most effectively.

Altering the surface area

It is very important for the enzymes of the digestive system to have the largest possible surface area of food to work on. This is not a problem with carbohydrates and proteins. However, the fats that you eat do not mix with all the watery liquids in your digestive system. They stay as large globules (like oil in water) that make it difficult for the lipase enzymes to act.

This is the second important function of the bile – it emulsifies the fats in your food. This means bile physically breaks up large drops of fat into smaller droplets. This provides a much bigger surface area of fats for the lipase enzymes to act upon. The larger surface area helps the lipase chemically break down the fats more quickly into fatty acids and glycerol.

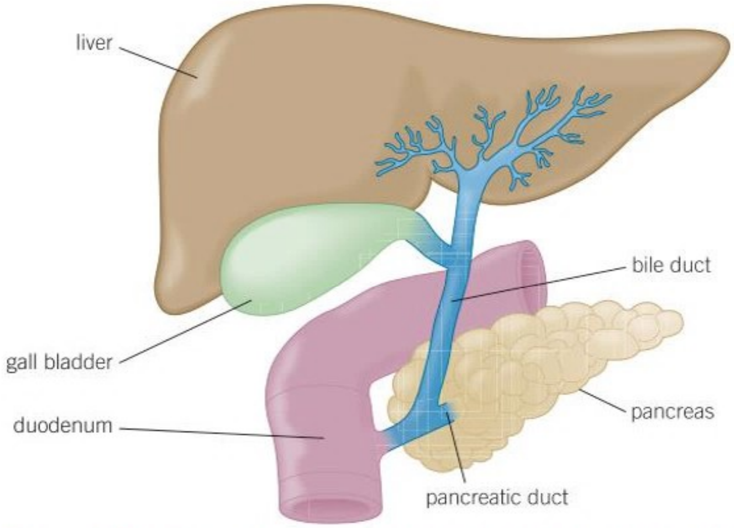


Figure 2 *Bile drains down small bile ducts in the liver. Most of it is stored in the gall bladder until it is needed*

Sometimes gall stones form and they can block the gall bladder and bile ducts. The stones can range from a few millimetres to several centimetres in diameter and can cause terrible pain. They can also stop bile being released onto the food and reduce the efficiency of digestion.

Study tip

Understand that:

- Hydrochloric acid gives the stomach a low pH suitable for the protease secreted there to work efficiently.
- Alkaline bile neutralises the acid and gives a high pH for the enzymes from the pancreas and small intestine to work well.
- Bile is *not* an enzyme as it does *not* break down fat molecules. Instead it emulsifies the fat into tiny droplets, which increases the surface area for lipase to increase the rate of digestion.

Figure 3 *Gall stones can be very large and can cause extreme pain*

1 Look at Figure 1 in Topic B3.6
  a Name the conditions needed for the protease enzyme pepsin from the stomach to work best. [1 mark]
  b Describe how your body creates the right pH in the stomach for this enzyme. [2 marks]
  c Describe in what conditions the proteases in the small intestine work best. [1 mark]
  d Describe how your body creates the right pH in the small intestine for these enzymes. [2 marks]

2 **a** Describe how bile results in a large surface area for lipase to work. [2 marks]
  b Explain why this is important. [3 marks]

3 Describe the passage of a meal containing bread through your digestive system. Your description should include everything you have learnt about digestion in Chapter B3. [6 marks]

Key points

- The protease enzymes of the stomach work best in acid conditions. The stomach produces hydrochloric acid, which maintains a low pH.
- The enzymes made in the pancreas and the small intestine work best in alkaline conditions.
- Bile produced by the liver, stored in the gall bladder, and released through the bile duct neutralises acid and emulsifies fats.

Summary questions

1

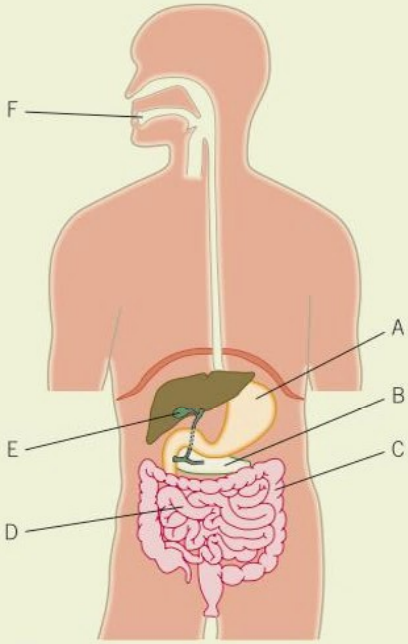


Figure 1

- **a** What is an organ system? [1 mark]
- **b** Name the parts of the human digestive system labelled A–F in Figure 1. [6 marks]
- **c** Select an example of an individual tissue that you would find in an organ of the digestive system and explain how it is specialised for its role. [4 marks]

2 **a** Describe the difference between a simple sugar and a complex carbohydrate. [2 marks]

- **b** Explain why carbohydrates are so important in the body. [2 marks]
- **c** Explain carefully how you would test for a simple sugar such as glucose. [4 marks]

3 The results in these tables come from a student who was investigating the breakdown of hydrogen peroxide using manganese(IV) oxide and grated raw potato.

Table 1 *Using manganese(IV) oxide*

Temperature in °C	Time taken in s
20	106
30	51
40	26
50	12

Table 2 *Using raw grated potato*

Temperature in °C	Time taken in s
20	114
30	96
40	80
50	120
60	no reaction

- **a** Draw a graph of the results using manganese(IV) oxide. [4 marks]
- **b** Explain what these results tell you about the effect of temperature on a catalysed reaction. Explain your observation. [3 marks]
- **c** Draw a graph of the results when raw grated potato was added to the hydrogen peroxide. [4 marks]
- **d** What is the name of the enzyme found in living cells that catalyses the breakdown of hydrogen peroxide? [1 mark]
- **e** What does this graph tell you about the effect of temperature on an enzyme-catalysed reaction? [2 marks]
- **f** Explain the difference between the reactions catalysed by an enzyme and by manganese(IV) oxide. [4 marks]
- **g** How could you change the second investigation to find the temperature at which the enzyme works best? [1 mark]

4 Students added samples of two protease enzymes, A and B, to test tubes containing solutions at a range of pH values. After 20 minutes they tested the protease activity in each tube. The table shows their results.

pH of solution in test tube	2	4	6	8	10	12
Activity of enzyme A	0	0	12	32	24	8
Activity of enzyme B	26	20	6	0	0	0

- **a** Name two variables that the students should have controlled in this investigation. [2 marks]
- **b** Name one way the students could have improved the quality of the data they collected. [1 mark]
- **c** What conclusions can the students make from these results about the enzymes A and B? [4 marks]
- **d** The students are told that the two enzymes are pepsin from the stomach and trypsin from the pancreas. Suggest which letter represents which enzyme. Give reasons for your answer. [6 marks]

Practice questions

01 Use the correct words from the box to complete each sentence.

a cell an organ an organism an organ system a tissue

The basic building block of living organisms is called ……………………..

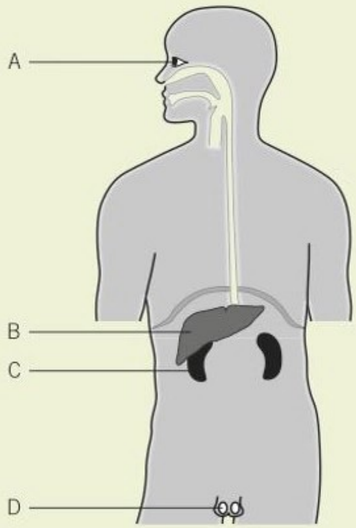
A group of cells with similar structure and function is called ………………………

The brain is an example of

……………………………… [3 marks]

02 **Figure 1** shows some organs of the human body.

Figure 1



02.1 Name organs **A**, **B**, **C,** and **D.** [4 marks]

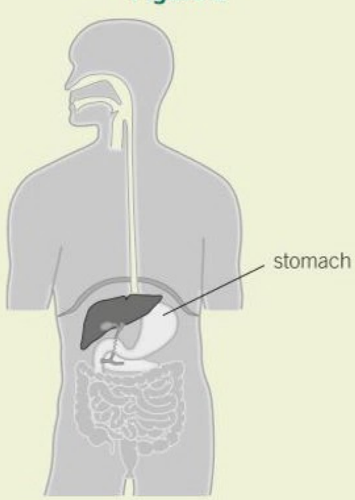
02.2 Which organ is part of the nervous system? [1 mark]

03 The digestive system is an example of an organ system.

03.1 What is an organ system? [1 mark]

Figure 2 shows a diagram of the digestive system.

Figure 2



03.2 Give the two main functions of the digestive system. [2 mark]

03.3 Protein digestion begins in the stomach. Explain how the stomach is adapted to digest protein. [3 marks]

04 Amylase is an enzyme that breaks down starch into sugar molecules.

A student investigated the effect of pH on the activity of amylase. The activity of amylase can be measured by how quickly the starch is digested.

The students used the following method.

- Mix amylase solution and starch suspension in a boiling tube.
- Put the boiling tube in a water bath at 37 °C.
- Remove a drop of the mixture from the tube every 30 seconds and test it for the presence of starch.
- Repeat the investigation at different pH values.

04.1 One control variable was the temperature. Explain why it was important to use the same temperature for each test. [2 marks]

04.2 Describe the test for the presence of starch and describe what result you would see if the test is positive. [2 marks]

04.3 What was the dependent variable in this investigation? [1 mark]

Table 1 shows the results of the investigation.

Table 1

pH	Time when no starch was detected in minutes
5.0	7.0
5.5	4.5
6.0	3.0
6.5	2.0
7.0	1.5
7.5	1.5
8.0	3.0

04.4 Plot the results on graph paper. Choose suitable scales, label both axes, and draw a line of best fit. [4 marks]

04.5 What is the optimum pH for this enzyme's activity? [1 mark]

04.6 Suggest **two** reasons why this conclusion may not be valid. [2 marks]

B

4 Organising animals and plants

4.1 The blood

Learning objectives

After this topic, you should know:

- how substances are transported to and from the cells
- that blood is made up of many different components
- the functions of each main component of blood.

Synoptic links

To find out more about how digested food gets into the transport system see Topic B3.6.

To find out more about how oxygen and carbon dioxide enter or leave the blood, see Topic B4.5.

To learn how oxygen is used in the cells and how carbon dioxide is produced, read Topic B9.1.

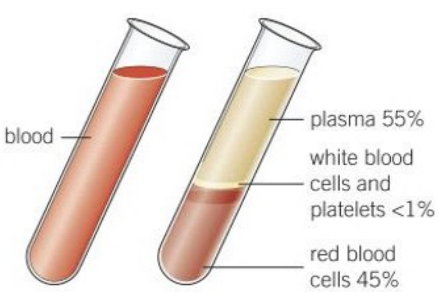


Figure 1 *The main components of blood. The red colour of your blood comes from the red blood cells*

Multicellular organisms with a small surface area to volume ratio often have specialised transport systems. The human circulatory system consists of the blood, the blood vessels, and the heart.

The components of the blood

Your blood is a unique tissue, based on a liquid called **plasma**. Plasma carries **red blood cells**, **white blood cells**, and **platelets** suspended in it. It also carries many dissolved substances around your body. The average person has between 4.7 and 5 litres of blood.

The blood plasma as a transport medium

Your blood plasma is a yellow liquid. The plasma transports all of your blood cells and some other substances around your body.

- Waste carbon dioxide produced by the cells is carried to the lungs.
- **Urea** formed in your liver from the breakdown of excess proteins is carried to your kidneys where it is removed from your blood to form urine.
- The small, soluble products of digestion pass into the plasma from your small intestine and are transported to the individual cells.

Red blood cells

There are more red blood cells than any other type of blood cell in your body – about 5 million in each cubic millimetre of blood. These cells pick up oxygen from the air in your lungs and carry it to the cells where it is needed. Red blood cells have adaptations that make them very efficient at their job:

- They are biconcave discs. Being concave (pushed in) on both sides, gives them an increased surface area to volume ratio for diffusion.
- They are packed with a red pigment called **haemoglobin** that binds to oxygen.
- They have no nucleus, making more space for haemoglobin.

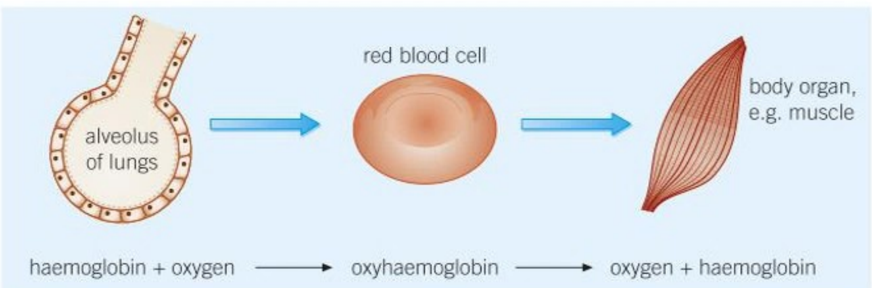


Figure 2 *The reversible reaction between oxygen and haemoglobin makes life as we know it possible by carrying oxygen to all the places where it is needed*

White blood cells

White blood cells are much bigger than red blood cells and there are fewer of them. They have a nucleus and form part of the body's defence system against harmful microorganisms. Some white blood cells (lymphocytes) form antibodies against microorganisms. Some form antitoxins against poisons made by microorganisms. Yet others (phagocytes) engulf and digest invading bacteria and viruses.

Platelets

Platelets are small fragments of cells. They have no nucleus. They are very important in helping the blood to clot at the site of a wound. Blood clotting is a series of enzyme-controlled reactions that result in converting fibrinogen into fibrin. This produces a network of protein fibres that capture lots of red blood cells and more platelets to form a jelly-like clot that stops you bleeding to death. The clot dries and hardens to form a scab. This protects the new skin as it grows and stops bacteria entering the body through the wound.

Figure 3 *Blood plasma is a yellow liquid that transports everything you need – and need to get rid of – around your body*

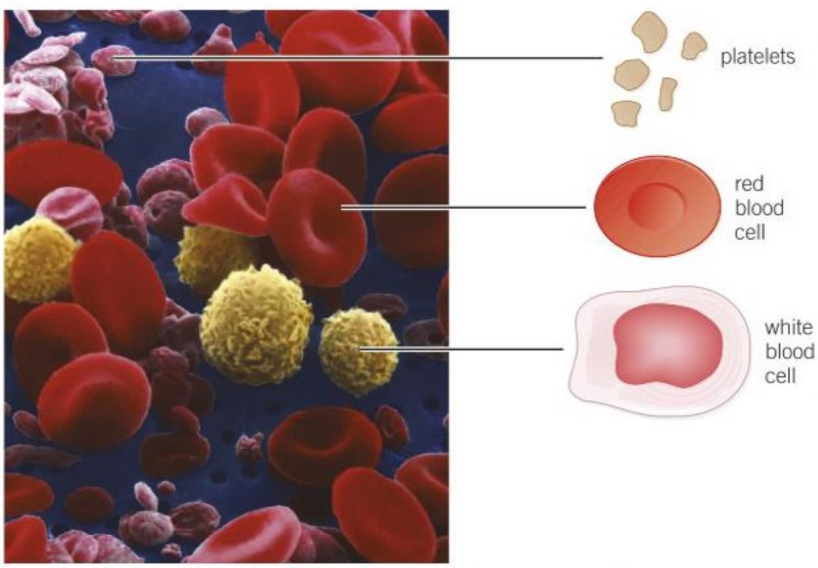


Figure 4 *Red blood cells, white blood cells, and platelets are suspended in the blood plasma*

1 Name three functions of the blood. [3 marks]

2 a Explain why it is not accurate to describe the blood as a red liquid. [2 marks]

b What actually makes the blood red? [1 mark]

c Identify three important functions of blood plasma. [3 marks]

3 Describe the main ways in which the blood helps you to avoid infection. Include a description of the parts of the blood involved. [6 marks]

Key points

- The blood, blood vessels, and heart make up the human circulatory system which transports substances to and from the body cells.
- Plasma has blood cells suspended in it and transports proteins and other chemicals around the body.
- Your red blood cells contain haemoglobin that binds to oxygen to transport it from the lungs to the tissues.
- White blood cells help to protect the body against infection.
- Platelets are cell fragments that start the clotting process at wound sites.

B4.2 The blood vessels

Learning objectives

After this topic, you should know:

- how the blood flows round the body
- that there are different types of blood vessels
- why valves are important
- the importance of a double circulatory system.

Blood flow

You can practise finding your pulse in the arteries that run close to the surface of the body in your wrist and in your neck.

You can find the valves in the veins in your hands, wrists, and forearms and see how the valves prevent the blood flowing backwards.

The substances transported in the blood need to reach the individual cells. Every cell in your body is within 0.05 mm of a capillary – the tiniest blood vessels in your circulatory system.

The blood vessels

Blood is carried around your body in three main types of blood vessels, each adapted for a different function.

- Your **arteries** carry blood away from your heart to the organs of your body. This blood is usually bright-red oxygenated blood. The arteries stretch as the blood is forced through them and go back into shape afterwards. You can feel this as a pulse where the arteries run close to the skin's surface (e.g., at your wrist). Arteries have thick walls containing muscle and elastic fibres. As the blood in the arteries is under pressure, it is very dangerous if an artery is cut, because the blood will spurt out rapidly every time the heart beats.
- The **veins** carry blood away from the organs towards your heart. This blood is usually low in oxygen and therefore a deep purple-red colour. Veins do not have a pulse. They have much thinner walls than arteries and often have valves to prevent the backflow of blood. The valves open as the blood flows through them towards the heart, but if the blood starts to flow backwards the valves close and prevent a backflow of blood. The blood is squeezed back towards the heart by the action of the skeletal muscles (Figure 2).
- Throughout the body, **capillaries** form a huge network of tiny vessels linking the arteries and the veins. Capillaries are narrow with very thin walls. This enables substances, such as oxygen and glucose, to diffuse easily out of your blood and into your cells. The substances produced by your cells, such as carbon dioxide, pass easily into the blood through the walls of the capillaries.

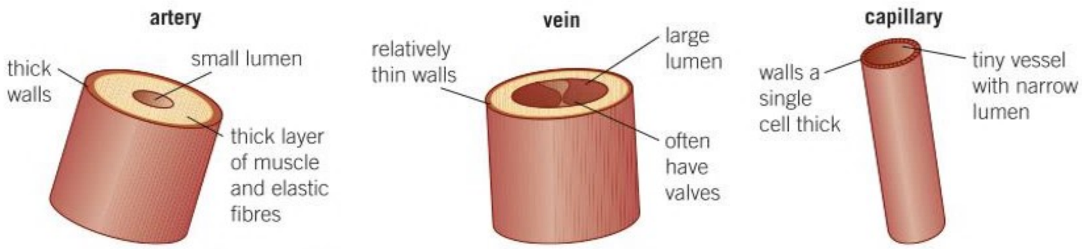


Figure 1 *The three main types of blood vessels*

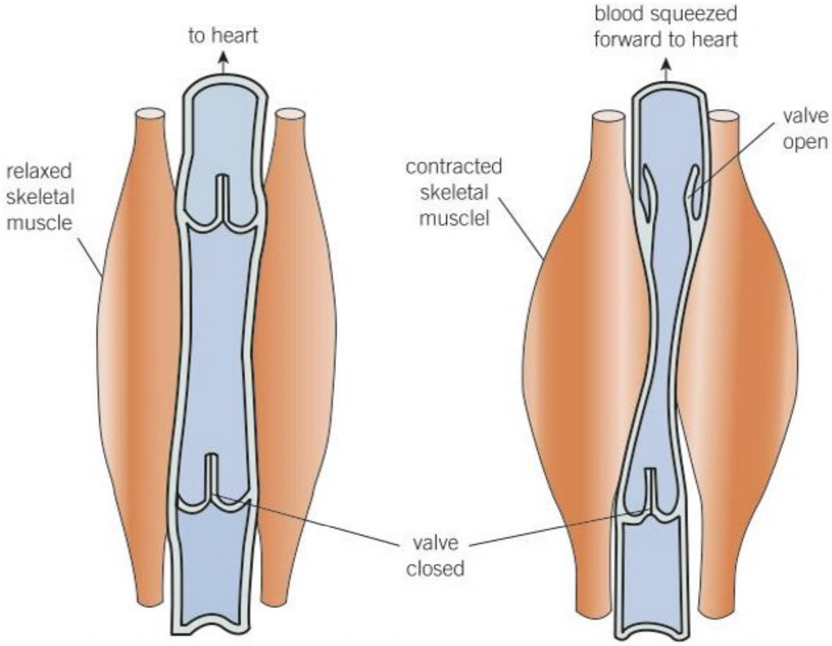


Figure 2 *How the valves and the muscles between them ensure that blood is moved from the body towards the heart*

In your circulatory system, arteries carry blood away from your heart to the organs of the body. Blood returns to your heart in the veins. The two are linked by the capillary network.

Double circulation

In humans and other mammals the blood vessels are arranged into a **double circulatory system**.

- One transport system carries blood from your heart to your lungs and back again. This allows oxygen and carbon dioxide to be exchanged with the air in the lungs.
- The other transport system carries blood from your heart to all other organs of your body and back again.

A double circulation like this is vital in warm-blooded, active animals such as humans. It makes our circulatory system very efficient. Fully oxygenated blood returns to the heart from the lungs. This blood can then be sent off to different parts of the body at high pressure, so more areas of your body can receive fully oxygenated blood quickly.

1 Name the function of each of the following blood vessels. Describe how the structure of the blood vessel relates to its function.
  a arteries [3 marks]
  b veins [3 marks]
  c capillaries. [2 marks]

2 **a** Describe how the heart, arteries, veins, and capillaries are linked together in the circulatory system. [2 marks]
  b Describe what happens in capillaries in a cell. [2 marks]

3 Fish have a single circulation system. The blood goes from the heart, through the gills, around the body, and back to the heart. Describe the disadvantages of a single circulation system like this for an active land mammal such as a human being. [4 marks]

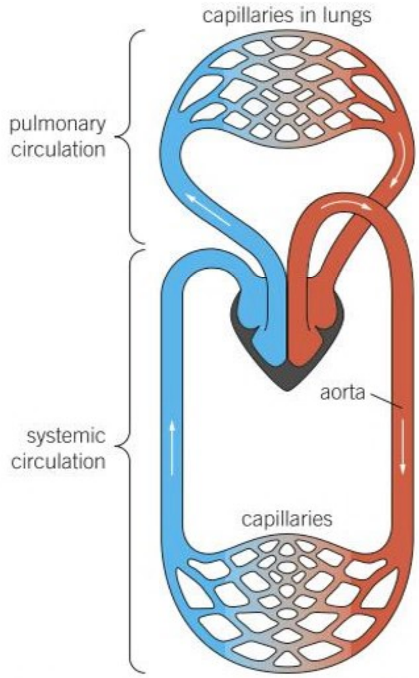


Figure 3 *The two separate circulation systems supply the lungs and the rest of the body*

Study tip

Remember:

Arteries carry blood away from the heart, and veins carry blood back to the heart – this applies to the circulation system of the lungs as well!

Key points

- Blood flows around the body in the blood vessels. The main types of blood vessels are arteries, veins, and capillaries.
- Substances diffuse in and out of the blood in the capillaries.
- The valves prevent backflow, ensuring that blood flows in the right direction.
- Human beings have a double circulatory system.

B4.3 The heart

Learning objectives

After this topic, you should know:

- the structure and functions of the heart
- ways of solving problems with the blood supply to the heart and problems with valves.

Your heart is the organ that pumps blood around your body. It is made up of two pumps (for the double circulation) that beat together about 70 times each minute. The walls of your heart are almost entirely muscle. This muscle is supplied with oxygen by the **coronary arteries**.

The heart as a pump

The structure of the human heart is perfectly adapted for pumping blood to your lungs and your body. The two sides of the heart fill and empty at the same time, giving a strong, coordinated heartbeat. Blood enters the top chambers of your heart, which are called the **atria**. The blood coming into the right atrium from the **vena cava** is deoxygenated blood from your body. The blood coming into the left atrium in the **pulmonary vein** is oxygenated blood from your lungs. The atria contract together and force blood down into the **ventricles**. Valves close to stop the blood flowing backwards out of the heart.

- The ventricles contract and force blood out of the heart.
- The right ventricle forces deoxygenated blood to the lungs in the **pulmonary artery**.
- The left ventricle pumps oxygenated blood around the body in a big artery called the **aorta**.

As the blood is pumped into the pulmonary artery and the aorta, valves close to make sure the blood flows in the right direction. The noise of the heartbeat you hear through a stethoscope is the sound of the valves of the heart closing to prevent the blood flowing backwards.

The muscle wall of the left ventricle is noticeably thicker than the wall of the right ventricle. This allows the left ventricle to develop the pressure needed to force the blood through the arterial system all over your body. The blood leaving the right ventricle moves through the pulmonary arteries to your lungs, where high pressure would damage the delicate capillary network where gas exchange takes place.

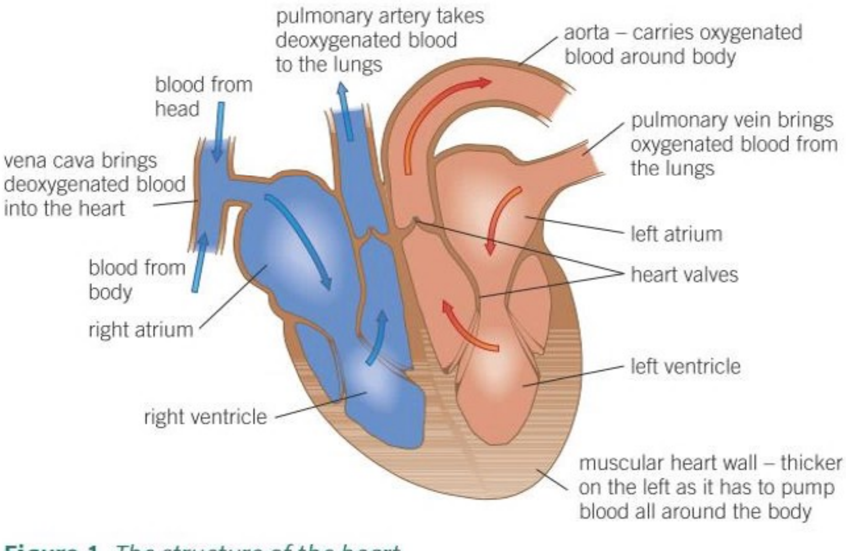


Figure 1 *The structure of the heart*

Problems with blood flow through the heart

In coronary heart disease the coronary arteries that supply blood to the heart muscle become narrow. A common cause is a buildup of fatty material on the lining of the vessels. If the blood flow through the coronary arteries is reduced, the supply of oxygen to the heart muscle is also reduced. This can cause pain, a heart attack, and even death.

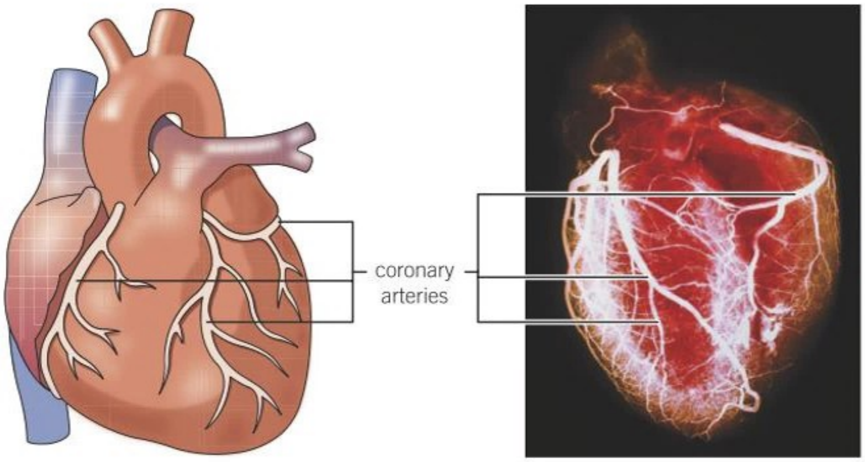


Figure 2 *The muscles of the heart work hard so they need a good supply of oxygen and glucose. This is supplied by the blood in the coronary arteries*

Doctors often solve the problem of coronary heart disease with a **stent**. A stent is a metal mesh that is placed in the artery. A tiny balloon is inflated to open up the blood vessel and the stent at the same time. The balloon is deflated and removed but the stent remains in place, holding the blood vessel open. As soon as this is done, the blood in the coronary artery flows freely. Doctors can put a stent in place without a general anaesthetic.

Stents can be used to open up a blocked artery almost anywhere in the body. Many stents also release drugs to prevent the blood clotting, although some studies suggest that the benefits do not justify the additional expense.

Doctors can also carry out bypass surgery, replacing the narrow or blocked coronary arteries with bits of veins from other parts of the body. This works for badly blocked arteries where stents cannot help. The surgery is expensive and involves the risk associated with a general anaesthetic.

Increasingly doctors prescribe **statins** to anyone at risk from cardiovascular disease. They reduce blood cholesterol levels and this slows down the rate at which fatty material is deposited in the coronary arteries.

1 Draw a flow chart to show how blood passes through the heart. [4 marks]

2 Explain the importance of the following in making the heart an effective pump in the circulatory system of the body:
  a heart valves [2 marks]
  b coronary arteries [2 marks]
  c the thickened muscular wall of the left ventricle. [3 marks]

3 Blood in the arteries is usually bright red because it is full of oxygen. This is not true of the blood in the pulmonary arteries. Explain this observation. [3 marks]

4 **a** Describe what a stent is. [2 marks]
  b Construct a table to show the advantages and disadvantages of using a stent to improve the blood flow through the coronary arteries compared with bypass surgery. [4 marks]

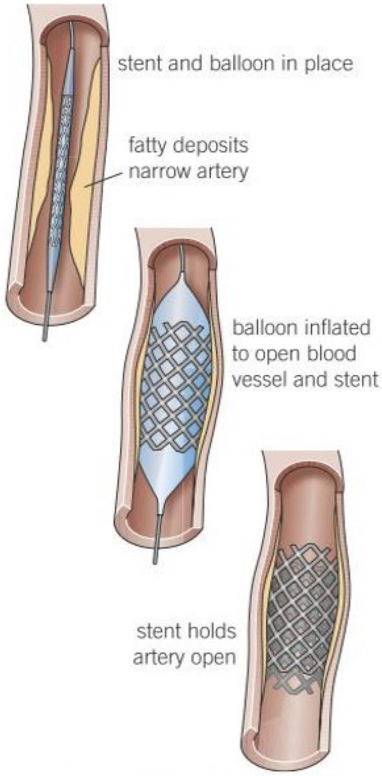


Figure 3 *A stent being positioned in an artery*

Study tip

Remember:

- the heart has *four* chambers
- ventricles pump blood *out* of the heart
- blood comes from the veins into the atria, through valves to the ventricles, and then out via arteries.

Key points

- The heart is an organ that pumps blood around the body.
- Heart valves keep the blood flowing in the right direction.
- Stents can be used to keep narrowed or blocked arteries open.
- Statins reduce cholesterol levels in the blood, reducing the risk of coronary heart disease.

B4.4 Helping the heart

Learning objectives

After this topic, you should know:

- how the heart keeps its natural rhythm
- how artificial pacemakers work
- what artificial hearts can do.

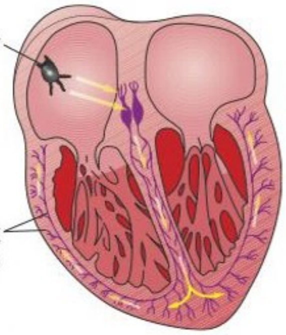


Figure 1 *The pacemaker region controls the basic rhythm of your heart*

The heart can be affected by a number of problems. Doctors, scientists, and engineers have worked out some amazing ways to help solve them.

Leaky valves

Heart valves have to withstand a lot of pressure. Over time they may start to leak or become stiff and not open fully, making the heart less efficient. People affected may become breathless and without treatment, will eventually die.

Doctors can operate and replace faulty heart valves. Mechanical valves are made of materials such as titanium and polymers. They last a very long time. However, with a mechanical valve you have to take medicine for the rest of your life to prevent your blood from clotting around it. Biological valves are based on valves taken from animals such as pigs or cattle, or even human donors. These work extremely well and the patient does not need any medication. However, they only last about 12–15 years.

Artificial pacemakers

The resting rhythm of a healthy heart is around 70 beats a minute. It is controlled by a group of cells found in the right atrium of your heart that acts as your natural pacemaker (Figure 1). If the natural pacemaker stops working properly, this can cause serious problems. If the heart beats too slowly, the person affected will not get enough oxygen. If the heart beats too fast, it cannot pump blood properly.

Problems with the rhythm of the heart can often be solved using an artificial pacemaker. This is an electrical device used to correct irregularities in the heart rate, which is implanted into your chest. Artificial pacemakers only weigh between 20 and 50 g, and they are attached to your heart by two wires. The artificial pacemaker sends strong, regular electrical signals to your heart that stimulate it to beat properly. Modern pacemakers are often very sensitive to what your body needs and only work when the natural rhythm goes wrong. Some even stimulate the heart to beat faster when you exercise.

Go further

The natural pacemaker regions of the heart are very complex. Doctors and scientists are developing ever more complex pacemakers to try and mimic the natural responses of the heart as closely as possible.

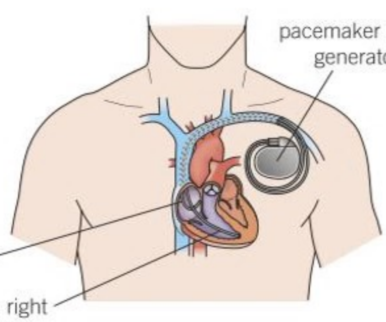


Figure 2 *An artificial pacemaker is positioned under the skin of the chest with wires running to the heart itself*

If you have a pacemaker fitted, you will need regular medical check-ups throughout your life. However, most people feel that this is a small price to pay for the increase in the quality and length of life that a pacemaker brings.

Artificial hearts

An artificial pacemaker may keep the heart beating steadily, but sometimes it is not enough to restore a person's health. When the heart fails completely, a donor heart or heart and lungs can be transplanted. When people need a heart transplant, they have to wait for a donor heart that is a tissue match. As a result of this wait, many people die before they get a chance to have a transplant.

Scientists have developed temporary hearts that can support your natural heart until it can be replaced. Although replacing your heart permanently with a machine is still a long way off, by 2015 almost 1500 people worldwide had been fitted with a completely artificial heart. These artificial hearts need a lot of machinery to keep them working. Most patients have to stay in hospital until they have their transplant.

In the past few years artificial hearts have improved considerably although there is always a risk of the blood clotting in an artificial heart, which can lead to death. However, this new technology gives people a chance to live a relatively normal life while they wait for a heart transplant. In 2011, 40-year-old Matthew Green became the first UK patient to leave hospital and go home with a completely artificial heart carried in a backpack. This kept him alive for two years until he had a heart transplant and no longer needed this life-saving machine.

Artificial hearts can also be used to give a diseased heart a rest, so that it can recover. Patients have a part or whole artificial heart implanted that removes the strain of keeping the blood circulating for a few weeks or months. However, the resources needed to develop artificial hearts and the cost of each one means they are not yet widely used in patients.

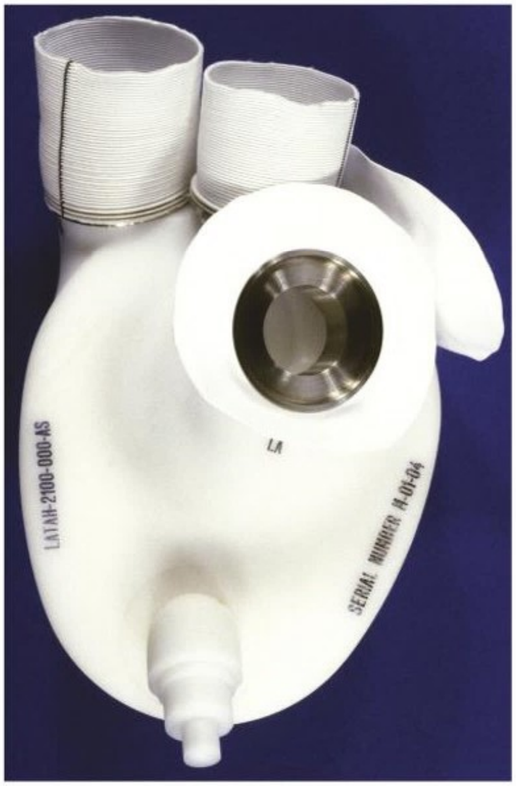


Figure 3 *This amazing artificial heart uses air pressure to pump blood around the body*

1 Describe what a natural pacemaker is. [2 marks]

2 Describe how an artificial pacemaker works. [3 marks]

3 **a** Explain how a leaky heart valve can cause health issues. [4 marks]

b Give one advantage and one disadvantage of:

i a biological replacement heart valve [2 marks]

ii a mechanical replacement heart valve. [2 marks]

4 Evaluate some of the scientific and social arguments for and against the continued development of artificial hearts. [6 marks]

Key points

- Damaged heart valves can be replaced using biological or mechanical valves.
- The resting heart rate is controlled by a group of cells in the right atrium that form a natural pacemaker.
- Artificial pacemakers are electrical devices used to correct irregularities in the heart rhythm.
- Artificial hearts are occasionally used to keep patients alive while they wait for a transplant, or for their heart to rest as an aid to recovery.

B4.5 Breathing and gas exchange

Learning objectives

After this topic, you should know:

- the structure of the human gas exchange system
- how gases are exchanged in the alveoli of the lungs.

For a gas exchange system to work efficiently, you need a large difference in concentrations of the gas on different sides of the exchange membrane (a steep concentration gradient). Many large animals, including humans, move air in and out of their lungs regularly. By changing the composition of the air in the lungs, they maintain a steep concentration gradient for both oxygen diffusing into the blood and carbon dioxide diffusing out of the blood. This is known as ventilating the lungs or breathing. It takes place in a specially adapted gas exchange system.

The gas exchange system

Your lungs are found in your chest (or thorax) and are protected by your ribcage. They are separated from the digestive organs beneath (in your abdomen) by the diaphragm. The diaphragm is a strong sheet of muscle. The job of your ventilation system is to move air in and out of your lungs, which provide an efficient surface for gas exchange in the alveoli (Figure 1). Ventilating the lungs is brought about by the contraction and relaxation of the intercostal muscles between the ribs and the diaphragm, changing the pressure inside the chest cavity so air is forced in or out of the lungs as a result of differences in pressure.

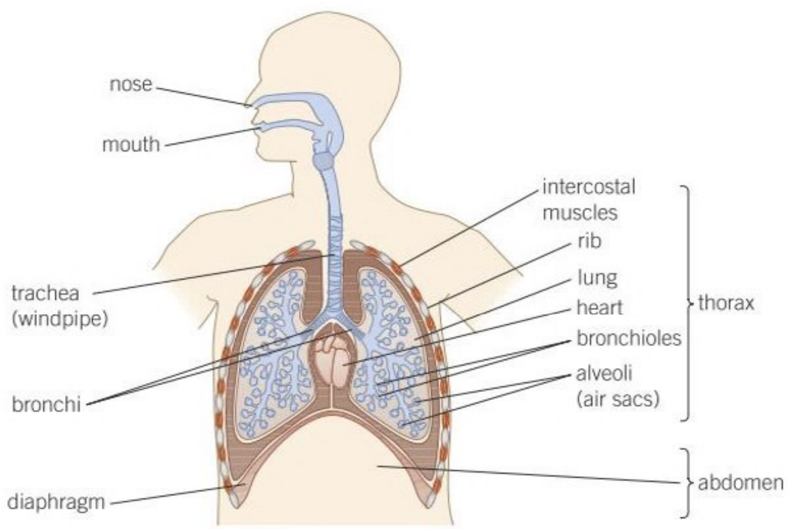


Figure 1 *The gas exchange system supplies your body with vital oxygen and removes waste carbon dioxide*

When you breathe in, oxygen-rich air moves into your lungs. This maintains a steep concentration gradient with the blood. As a result, oxygen continually diffuses into your bloodstream through the gas exchange surfaces of your alveoli. Breathing out removes carbon dioxide-rich air from the lungs. This maintains a concentration gradient so carbon dioxide can continually diffuse out of the bloodstream into the air in the lungs.

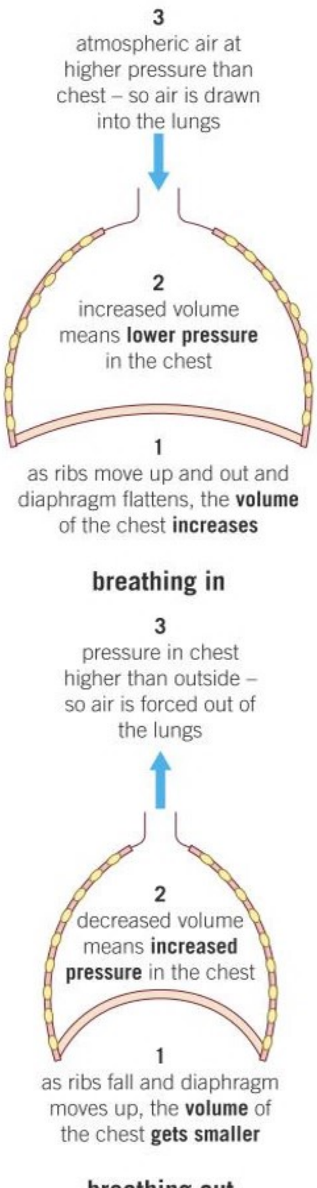


Figure 2 *Ventilation of the lungs*

Table 1 *The composition of inhaled and exhaled air (~ means approximately)*

Atmospheric gas	% of air breathed in	% of air breathed out
nitrogen	~80	~80
oxygen	~20	~16
carbon dioxide	0.04	~4

Adaptations of the alveoli

Your lungs are specially adapted to make gas exchange more efficient. They are made up of clusters of alveoli that provide a very large surface area. This is important for achieving the most effective diffusion of oxygen and carbon dioxide. The alveoli also have a rich supply of blood **capillaries**. This maintains a concentration gradient in both directions. The blood coming to the lungs is always relatively low in oxygen and high in carbon dioxide compared to the inhaled air.

As a result, gas exchange takes place down the steepest concentration gradients possible. This makes the exchange rapid and effective. The layer of cells between the air in the lungs and the blood in the capillaries is also very thin (only one cell wide). This allows diffusion to take place over the shortest possible distance. If all of the alveoli in your lungs were spread out flat, they would have a surface area equivalent to 10–15 table tennis tables.

Synoptic links

You can find out more about diffusion and concentration gradients in Topic B1.6 and about exchange surfaces in Topic B1.10.

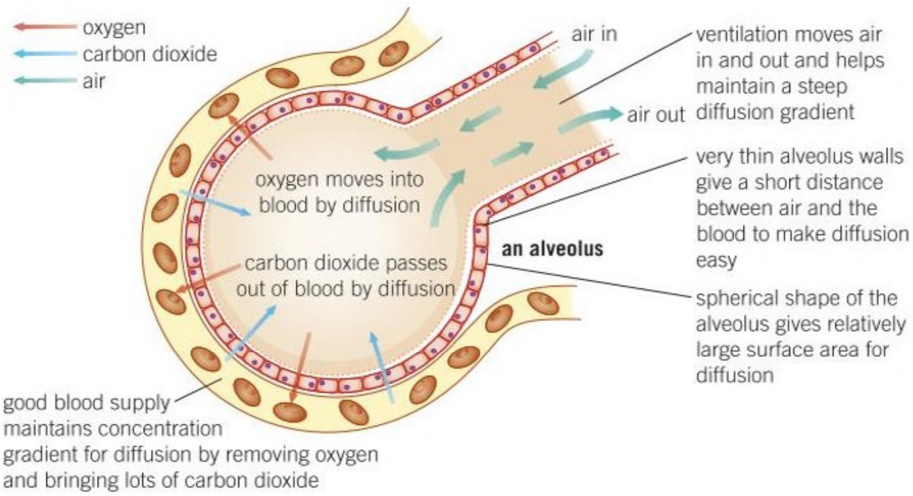


Figure 3 *The alveoli are adapted so that gas exchange can take place as efficiently as possible in the lungs*

1 Describe how air is moved in to and out of your lungs. [3 marks]

2 **a** Describe what is meant by the term gaseous exchange [1 mark]
b Explain why it is so important in your body. [2 marks]

3 **a** Draw a bar chart to show the difference in composition between the air you breathe in and the air you breathe out (use the data in Table 1). [3 marks]
b People often say we breathe in oxygen and breathe out carbon dioxide. Use your bar chart to explain why this is wrong. [2 marks]
c Describe the adaptations of the human gas exchange system and explain how they make it as efficient as possible. [6 marks]

Key points

- The lungs are in your chest cavity, protected by your ribcage and separated from your abdomen by the diaphragm.
- The alveoli provide a very large surface area and a rich supply of blood capillaries. This means gases can diffuse into and out of the blood as efficiently as possible.

B4.6 Tissues and organs in plants

Learning objectives

After this topic, you should know:

- the roots, stem, and leaves of a plant form a plant organ system for transport of substances around the plant.

Figure 1 *The flower of the elephant yam is a plant organ made up of a number of different tissues*

Elephant yams are plants that produce a large flower that releases a disgusting stench like rotting meat that attracts carrion beetles. The beetles become trapped in the flower – its slippery, waxy walls stop them escaping. Around 24 hours after the stench is released, the flower releases pollen that coats the trapped beetles. Then the walls of the flower change texture – they become rough so the beetles can crawl out, carrying the pollen to another flower, lured again by the powerful smell of dead meat. These flowers are one type of plant organ – they are temporary and for reproduction only. But as you will see, plants have other organs, made up of combinations of many different tissues.

Plant tissues

The specialised cells in multicellular plants are organised into tissues and organs. **Epidermal** tissues cover the surfaces and protect them. These cells often secrete a waxy substance that waterproofs the surface of the leaf. **Palisade mesophyll** tissue contains lots of chloroplasts, which carry out photosynthesis. **Spongy mesophyll** tissue contains some chloroplasts for photosynthesis but also has big air spaces and a large surface area to make the diffusion of gases easier. **Xylem** and **phloem** are the transport tissues in plants. Xylem carry water and dissolved mineral ions from the roots up to the leaves and phloem carry dissolved food from the leaves around the plant. You will learn more about the role of the xylem and phloem in Topic B4.7.

The meristem tissue at the growing tips of roots and shoots is made up of rapidly dividing plant cells that grow and differentiate into all the other cell types needed.

Plant organs

Within the body of a plant, specialised tissues such as palisade, spongy mesophyll, xylem, and phloem are arranged to form organs. Each organ carries out its own particular functions. The leaves, stems, and roots are all plant organs, each of which has a very specific job to do (Figure 2).

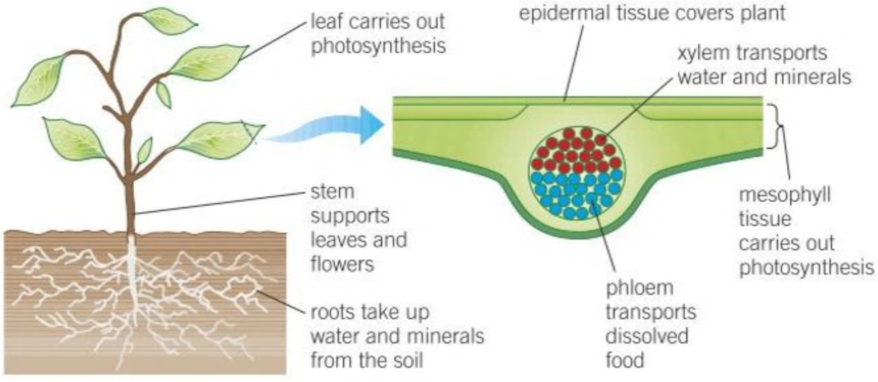


Figure 2 *Some of the main plant organs*

Within each plant organ there are collections of different tissues working together to perform specific functions for the organism.

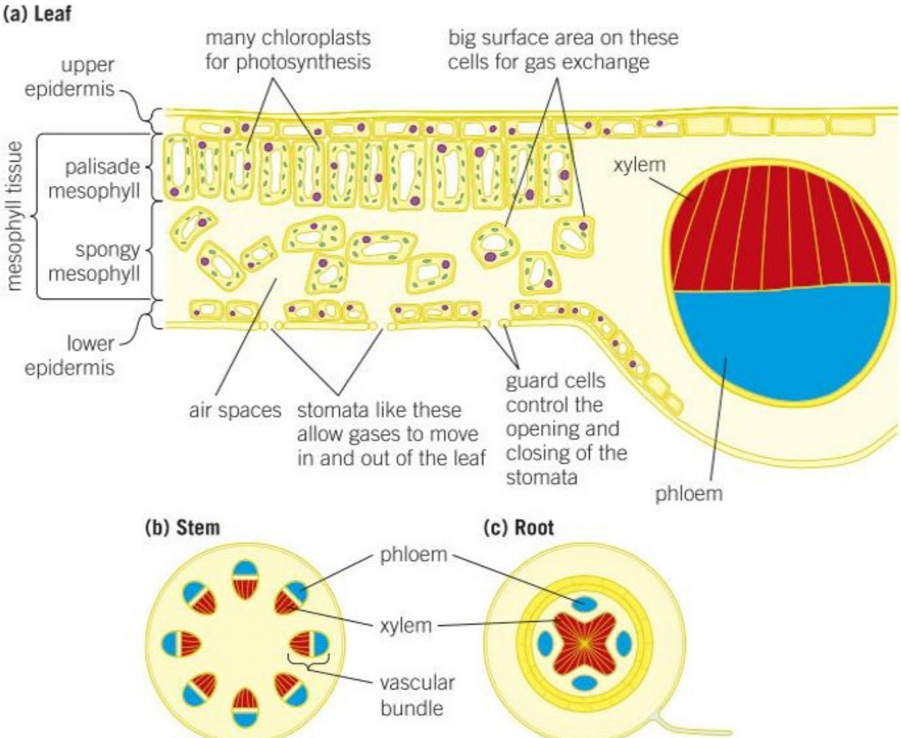


Figure 3 *Plants have specific tissues to carry out particular functions. They are arranged in organs such as the: **a** leaf, **b** stem, and **c** roots.*

Plant organs can be very large indeed. For example, some trees, such as the giant redwood, have trunks over 40 m tall. A plant cell is about 100 μm long. The plant stem is 400 000 times bigger than an individual cell.

Plant organ systems

The whole body of the plant – the roots, stem, and leaves – form an organ system for the transport of substances around the plant. Trees form the largest and oldest land organisms, so plant organ systems are also the biggest land based organ systems in the living world.

Go further

Many plants have specialised defence tissues and organs. For example, nettles have specialised hairs that act like hypodermic needles, injecting poison into any animal brushing past or attempting to eat them.

Synoptic links

You learnt about some of the specialised plant cells that make up plant tissues and organs in Topic B1.5, and about meristems in plants in Topic B2.3.

1 Plants contain specialised tissues that are adapted to their function. Explain how:
   a epidermal tissues protect the surface of the leaf [1 mark]
   b palisade mesophyll tissue is adapted for photosynthesis [1 mark]
   c spongy mesophyll tissue is adapted for photosynthesis. [1 mark]

2 Explain how the tissues in a leaf are arranged to form an effective organ for photosynthesis. [6 marks]

Key points

- Plant tissues are collections of cells specialised to carry out specific functions.
- The structure of the tissues in plant organs is related to their functions.
- The roots, stem, and leaves form a plant organ system for the transport of substances around the plant.

B4.7 Transport systems in plants

Learning objectives

After this topic, you should know:

- the substances that are transported in plants
- how transport in the xylem tissue differs from transport in the phloem tissue.

Synoptic link

For information on phloem and xylem cells, see Topic B1.5.

Figure 1 *Aphids take the liquid full of dissolved sugars directly from the phloem*

Plants make glucose (a simple sugar) by photosynthesis in the leaves and other green parts. This glucose is needed all over the plant. Similarly, water and mineral ions move into the plant from the soil through the roots, but they are needed by every cell of the plant. Plants have two separate transport systems to move substances around the whole plant.

Phloem – moving food

The phloem tissue transports the sugars made by photosynthesis from the leaves to the rest of the plant. This includes transport to the growing areas of the stems and roots where the dissolved sugars are needed for making new plant cells. Food is also transported to the storage organs where it provides an energy store for the winter.

Phloem is a living tissue – the phloem cells are alive. The movement of dissolved sugars from the leaves to the rest of the plant is called **translocation**.

Greenfly and other aphids are plant pests. They push their sharp mouthparts right into the phloem and feed on the sugary fluid. If too many of them attack a plant, they can kill it by taking all of its food.

Xylem – moving water and mineral ions

The xylem tissue is the other transport tissue in plants. It carries water and mineral ions from the soil around the plant to the stem and the leaves. Mature xylem cells are dead.

Evidence for movement through xylem

You can demonstrate the movement of water up the xylem by placing leafy celery stalks in water containing a coloured dye. After a few hours, slice the stem in several places – you will see coloured circles where the water and dye have moved through the xylem. You may also see patches of dye in the leaves where the water has entered the mesophyll cells for photosynthesis.

In woody plants like trees, the xylem makes up the bulk of the wood and the phloem is found in a ring just underneath the bark. This makes young trees particularly vulnerable to damage by animals – if a complete ring of bark is eaten, transport in the phloem stops and the tree will die.

Figure 2 *Without protective collars on the trunks, deer would destroy the transport tissue of young trees like these and kill them before they could become established in the woodland*

Why is transport so important?

It is vital to move the food made by photosynthesis around the plant – all the cells need sugars for respiration as well as for providing materials for growth. The movement of water and dissolved mineral ions from the roots is equally important – the mineral ions are needed for the production of proteins and other molecules within the cells.

The plant needs water for photosynthesis, the process in which carbon dioxide and water combine to make glucose (plus oxygen). The plant also needs water to hold itself upright. When a cell has plenty of water inside it, the vacuole presses the cytoplasm against the cell walls. This pressure of the cytoplasm against the cell walls gives support for young plants and for the structure of the leaves. For young plants and soft-stem plants (although not trees) this is the main method of support.

1. Explain why a plant needs a transport system. [1 mark]
2. Describe the main differences between xylem and phloem in a plant. [3 marks]
3. A local woodland trust has set up a scheme to put protective plastic covers around the trunks of young trees. Some local residents are objecting to this, saying it spoils the look of the woodland. Explain exactly why this protection is necessary and the impact it would have on the wood if the trees were not protected. [6 marks]

Figure 3 *The phloem and xylem are arranged in vascular bundles in the stem*

Study tip

Don't confuse xylem and phloem:

- For phloem think 'transports food' (sugar).
- For xylem think 'transports water'.

Key points

- Plants have separate transport systems.
- Xylem tissue transports water and mineral ions from the roots to the stems and leaves.
- Phloem tissue transports dissolved sugars from the leaves to the rest of the plant, including the growing regions and storage organs.

B4.8 Evaporation and transpiration

Learning objectives

After this topic, you should know:

- what transpiration is
- the role of stomata and guard cells in controlling gas exchange and water loss.

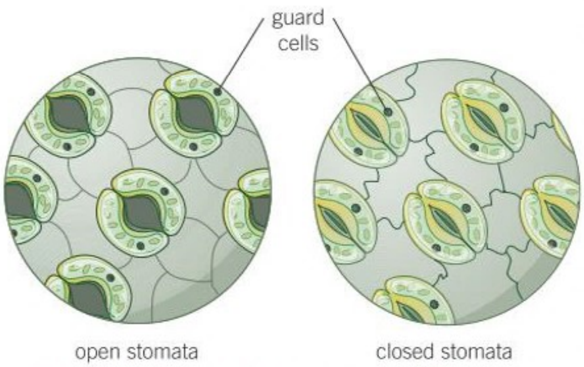


Figure 1 *The size of the opening of the stomata is controlled by the guard cells. This in turn controls the carbon dioxide going into the leaf and the water vapour and oxygen leaving it*

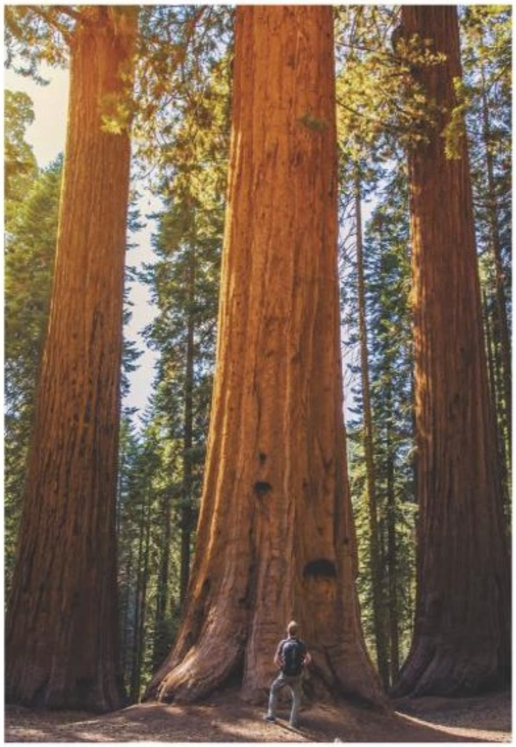


Figure 3 *The transpiration stream in trees can pull litres of water many metres above the ground*

The top of a tree may be many metres from the ground. Yet the leaves at the top need water just as much as those on the lower branches. So how do they get the water they need?

Water loss from the leaves

All over the leaf surface are small openings known as stomata. The stomata can be opened when the plant needs to allow air into the leaves. Carbon dioxide from the atmosphere diffuses into the air spaces and then into the cells down a concentration gradient. At the same time, oxygen produced by photosynthesis is removed from the leaf by diffusion into the surrounding air. This maintains a concentration gradient for oxygen to diffuse from the cells into the air spaces of the leaf. The size of the stomata and their opening and closing is controlled by the **guard cells** (Figure 1).

When the stomata are open, plants lose water vapour through them as well. The water vapour evaporates from the cells lining the air spaces and then passes out of the leaf through the stomata by diffusion. This loss of water vapour is known as **transpiration**.

As water evaporates from the surface of the leaves, more water is pulled up through the xylem to take its place. This constant movement of water molecules through the xylem from the roots to the leaves is known as the transpiration stream. It is driven by the evaporation of water from the leaves. So, anything that affects the rate of evaporation will also affect transpiration.

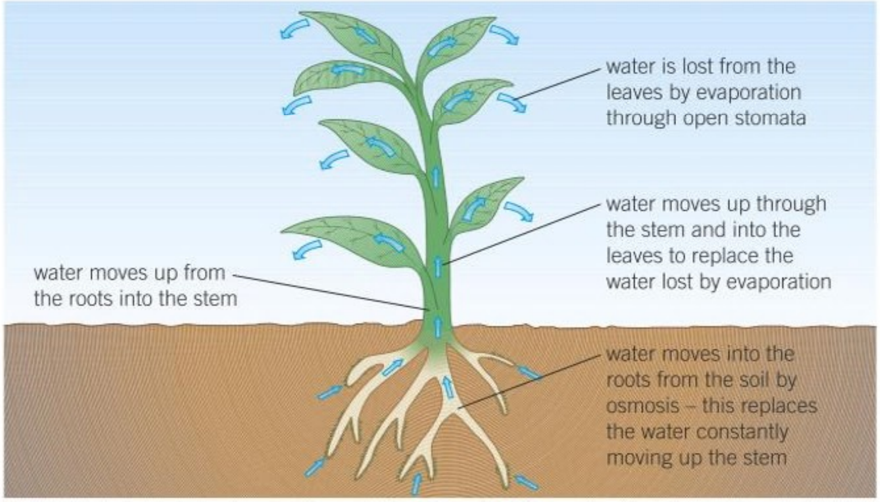


Figure 2 *The transpiration stream*

Most of the water vapour lost by plants is lost from the leaves. Most of this loss takes place by diffusion through the stomata when they are open. This is one of the main reasons why it is important that plants can close their stomata – to limit the loss of water vapour.