

**AQA**

# Biology

## Third edition



**Ann Fullick**

**Andrea Coates**

**Editor: Lawrie Ryan**

**OXFORD**



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# Biology

## Third edition

Ann Fullick

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# 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
<b>1 Using a light microscope.</b> Use a light microscope to observe, draw, and label a selection of plant and animal cells and include a scale magnification.	B1.2
<b>2 Investigating the effect of antiseptics or antibiotics on bacterial growth.</b> Use agar plates and measure the zones of inhibition produced around colonies.	B5.4
<b>3 Investigate the effect of a range of concentrations of salt or sugar solutions on the mass of plant tissue.</b> Investigate osmosis by measuring how the mass of plant tissue changes in a range of concentrations of salt or sugar solutions.	B1.8
<b>4 Use standard food tests to identify food groups.</b> Detect sugars, starch, and proteins in food using Benedict's test, the iodine test, and Biuret reagent.	B3.3
<b>5 Investigate the effect of pH on the rate of reaction of amylase enzyme.</b> 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
<b>6 Investigate the effect of light intensity on the rate of photosynthesis</b> Use an aquatic plant to observe the effect light intensity has on the rate of photosynthesis.	B8.2
<b>7 Investigate the effect of a factor on human reaction time.</b> Plan and carry out an investigation, choosing appropriate ways to measure reaction time and considering the risks and ethics of the investigation.	B10.2
<b>8 Investigate the effect of light or gravity on the growth of newly germinated seedlings.</b> Record results both as length measurements and as accurate, labelled biological drawings to show the effects.	B11.9
<b>9 Measure the population size of a common species in a habitat.</b> Use sampling techniques to investigate the effect of a factor on the distribution of this species.	B16.3
<b>10 Investigate the effect of temperature on the rate of decay of fresh milk.</b> 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  are only relevant to those who are sitting the higher tier exams.

## 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.

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.

## 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.

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  are for students sitting the higher tier exams.

Higher



more confidence in your data if the results are obtained by different investigators using different equipment, making your measurements repeatable.

The most important thing you are measuring is the actual thing you want to measure. If your data can be used to answer your original question, this seems very obvious, but it is not always easy to get this right. There may be other factors that affect your results that you can't see. Then remember that your investigation and hence the data you collect are only as good as the questions you ask.

**How might an independent variable be linked to a dependent variable?**

- The independent variable is the one you choose to vary in your investigation.

**How might an outcome variable be linked to a dependent variable?**

- The outcome variable is the one you choose to vary in your investigation.

These variables may be linked together. If there is a pattern to what happens, it may be that one thing happened after another has happened. It may be that:

- changing one variable changes another.

It may also be that there is no pattern between them, but there is still something else that is changing.

#### Starting an investigation

Starters use observations to ask questions. You can only use useful observations if they are accurate. If you have made mistakes, then start here at all of the answers, but you will have enough to start thinking the correct answers.

When you are choosing an investigation, you have to consider carefully which variables may be relevant to it.

#### Study tip

Observations, measurements, and predictions based on creative thinking and good scientific knowledge can lead to hypotheses.

Figure 1 Gas mask

A gas mask is used to protect people from breathing in dangerous substances. It is a form of personal protective equipment (PPE).

Figure 2 Safety glasses

Safety glasses are used to protect the eyes from damage or injury. They are made of clear plastic and are designed to fit over normal spectacles.

Figure 3 Laboratory glassware

Laboratory glassware is used to hold liquids and chemicals in a safe way. It is made of glass and is often used in chemistry experiments.

## Maths skills for Biology

### MS1 Arithmetic and numerical computation

#### Learning objectives

After this topic, you should know:

How to:

- recognise and use expressions involving percentages;
- recognise and use expressions involving fractions;
- use ratios, fractions and percentages;
- make estimates of the results of calculations.

#### 1a Decimal form

Most of the time we use decimal numbers to measure things, for example, when you make measurements in biology. This chapter will introduce you to some of the ways of writing numbers in decimal form.

When you make measurements in biology, the numbers you use will be whole numbers. In between whole numbers, there are fractions, decimal numbers, for example, the height of a toy could be 1.54 m, or the mass of a small number could be 0.75 g.

The value of each digit in a number is called its place value.

Thousands	Hundreds	Tens	Units	Decimals	Tenths	Hundredths	Thousands
1	0	0	0	.	7	5	0

#### 1b Standard form

Standard form is a way of writing very large or very small numbers. These numbers are written in a standard way, so that they are easier to work with.

Standard form is also called scientific notation. It is used in many fields of science, for example, in physics, to write down the mass of a very small particle.

It is a decimal number between 1 and 10 that is multiplied by 10, for example 7.0.

It is a decimal number. The power of ten is the positive or negative number of digits to the right of the decimal point.

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# Kerboodle

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

If your school 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

B1.9 Animation: Active transport  
Click play to start the animation.

Acknowledgements  
© Oxford University Press 2016

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

**AQA Biology GCSE Student checklist**

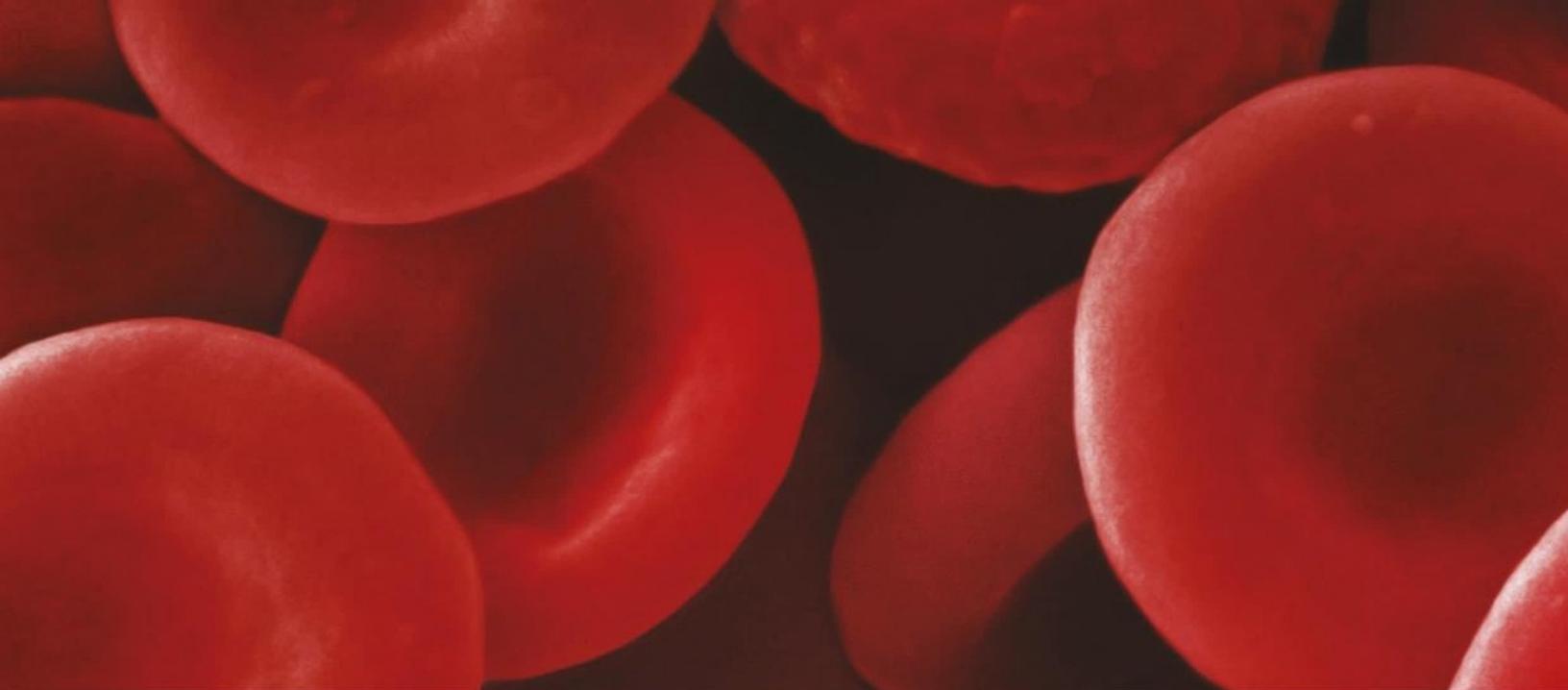
Name: \_\_\_\_\_ Class: \_\_\_\_\_ Date: \_\_\_\_\_ B2

**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 state that mitosis is a stage in cell division.	<input type="checkbox"/> I can explain why chromosomes in body cells are normally found in pairs. <input type="checkbox"/> I can describe situations where mitosis is occurring.	<input type="checkbox"/> I can explain why genetic material must be doubled during mitosis. <input type="checkbox"/> 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.	<input type="checkbox"/> I can use the keywords to describe the process of mitosis.	<input type="checkbox"/> 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 state why plant clones are genetically identical to each other.	<input type="checkbox"/> I can describe the importance of cell differentiation in multicellular organisms. <input type="checkbox"/> I can explain how using tissue culture creates a clone of a plant.	<input type="checkbox"/> I can compare and contrast differentiation in plants and animals. <input type="checkbox"/> 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.	<input type="checkbox"/> I can attempt to clone a plant by using the apparatus correctly and following safety rules.	<input type="checkbox"/> 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 state that plant stem cells can be used to create clones.	<input type="checkbox"/> I can describe differences between embryonic and adult stem cells. <input type="checkbox"/> I can explain why plant clones are.	<input type="checkbox"/> I can explain why embryonic stem cells are more useful for helping medical conditions. <input type="checkbox"/> I can write a well-structured article about stem cells.

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 **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...

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.

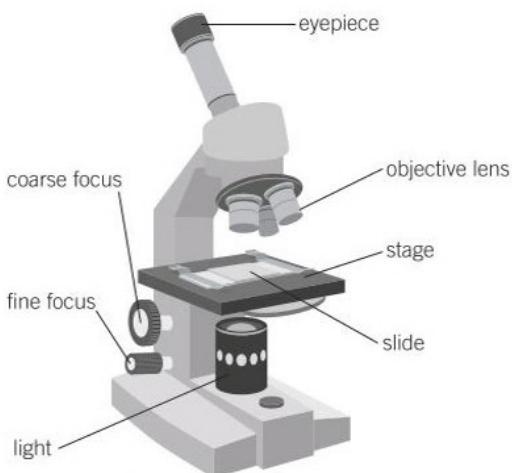


Figure 1 A light microscope

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 ( $\mu\text{m}$ )

1  $\mu\text{m}$  = 1000 nanometres (nm) – so a nanometre is 0.000 000 001 metres (or written in standard form as  $1 \times 10^{-9}$  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 ( $\times 2000$ ), 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 2000 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  $\times 4$  and your objective lens is  $\times 10$ , 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  $\times 40$ ).

### 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.

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

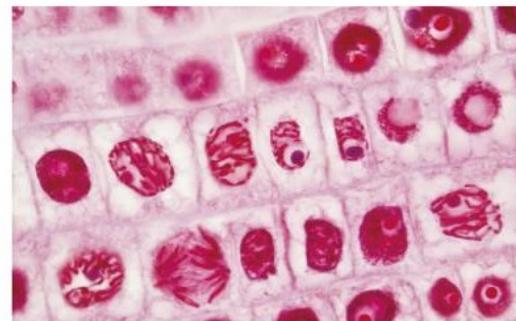
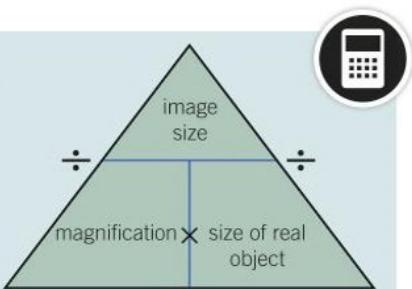
For example, if you know you are working at magnification  $\times 40$ , and the image of the cell you are looking at measures 1 mm, you can work out the actual diameter of the cell:

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

so

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

Your cell has a diameter of **25  $\mu\text{m}$** .



**Figure 2** Onion cells dividing as seen through a light microscope – magnification  $\times 570$



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

### 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!

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

- Name one advantage and one disadvantage of using:
  - a light microscope [2 marks]
  - b an electron microscope. [2 marks]
- A student measured the diameter of a human capillary on a micrograph. The image measures 5 mm and the student knows the magnification is  $\times 1000$ . How many micrometres is the diameter of the capillary? [3 marks]
- A student is told the image of the cell has a diameter of 800  $\mu\text{m}$ . The actual cell has a diameter of 20  $\mu\text{m}$ . At what magnification has the cell been observed? [2 marks]
- Evaluate the use of an electron microscope and a light microscope, giving one example where each type of microscope might be used. [6 marks]



# 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.

## Synoptic link

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



## Go further

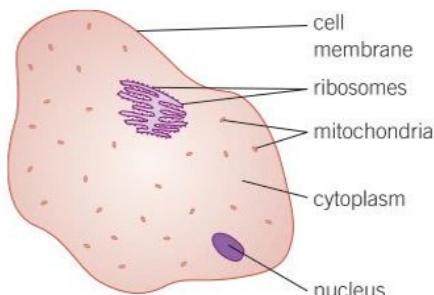
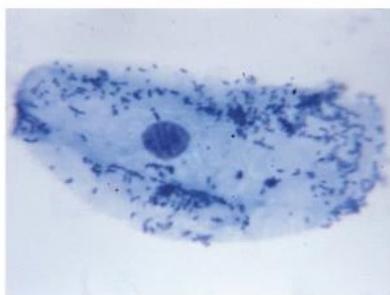
The ultrastructure of a cell – the details you can see under an electron microscope – includes structures such as the cytoskeleton, the Golgi apparatus, and the rough and smooth endoplasmic reticulum. They support and move the cell, modify and package proteins and lipids, and produce the chemicals that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

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  $10\text{--}30\ \mu\text{m}$  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.

- 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  $10\ \mu\text{m}$ .
- 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:  $1\text{--}2\ \mu\text{m}$  in length and only  $0.2\text{--}0.7\ \mu\text{m}$  in diameter.
- The **ribosomes** – where protein synthesis takes place, making all the proteins needed in the cell.



**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  $\times 1350$  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.

## Synoptic link



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

## 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  $100\ \mu\text{m}$  in length.

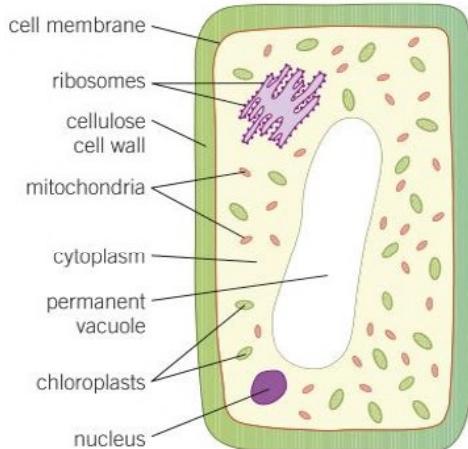
Plant cells have all the features of a typical animal cell, but they also contain features that are needed for their very different functions (Figures 2 and 3).

**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.

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]



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

### 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.

## 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.

## 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.

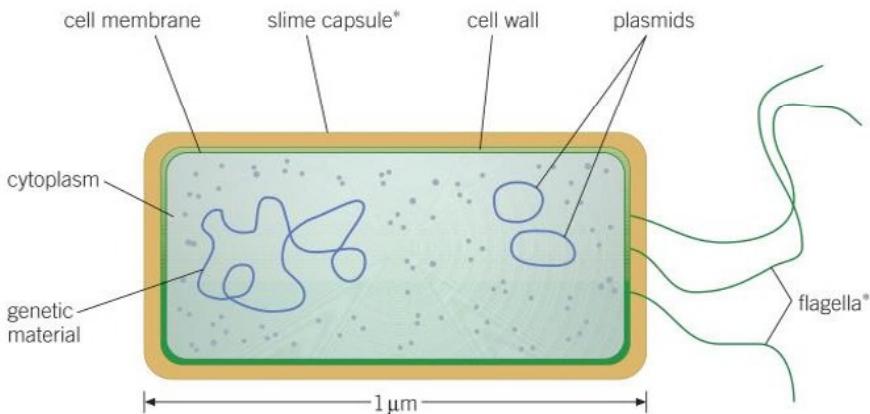
The genetic material is a chemical called DNA and this forms structures called chromosomes that are contained within the nucleus. All animals (including human beings), plants, fungi, and protista are eukaryotes.

## 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.



\*not always present

**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.

### 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.

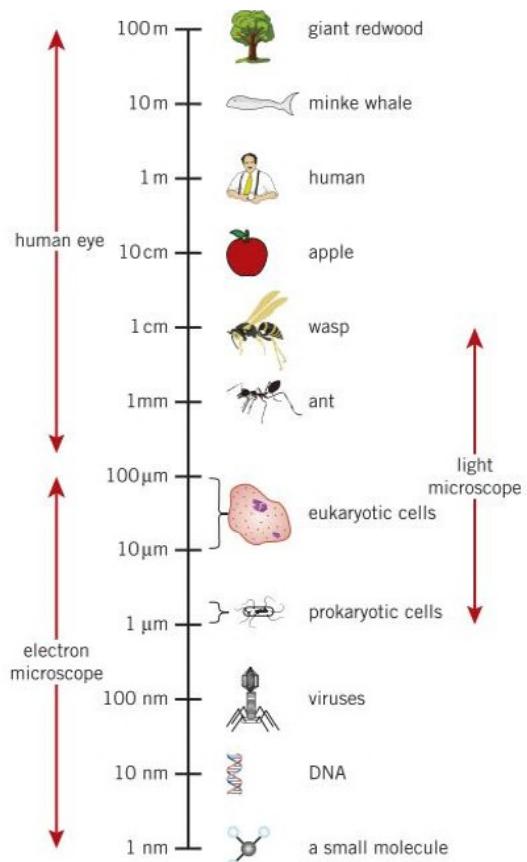
If the bigger number divided by the smaller number is around 100, then it is two orders of magnitude or  $10^2$  bigger.

#### Example:

A small animal cell has a length of around  $10\text{ }\mu\text{m}$ . A large plant cell has a length of around  $100\text{ }\mu\text{m}$ .

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

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



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

### Study tip

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

### Key points

- 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  $6\text{ }\mu\text{m}$ . 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]

- 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?

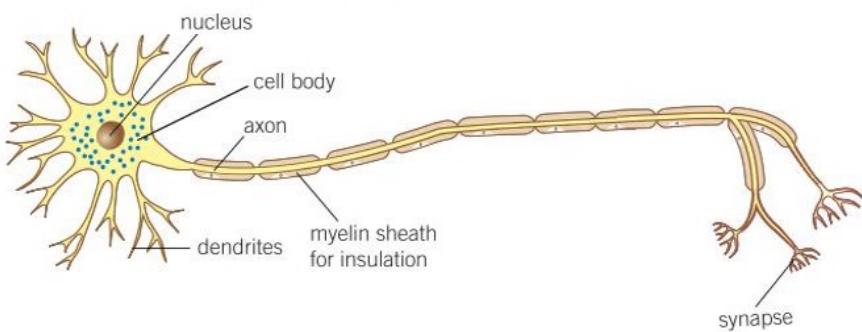
Although the smallest living organisms are only single cells, they can carry out all of the functions of life. Most organisms are bigger and are made up of lots of cells. Some of these cells become specialised to carry out particular jobs.

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.



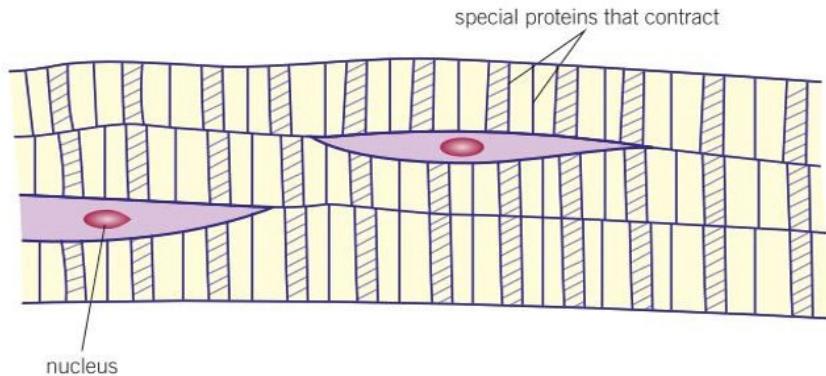
**Figure 1** A nerve cell is specialised to carry electrical impulses from one part of the body to another

## 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.



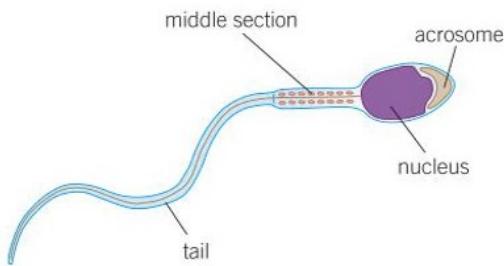
**Figure 2** A striated muscle cell is specialised to contract and relax

## 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  
**b** muscle cell  
**c** sperm cell

[2 marks]  
[2 marks]  
[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.

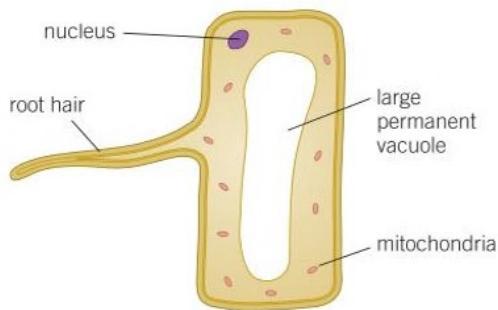


Figure 1 A root hair cell

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.

### 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.

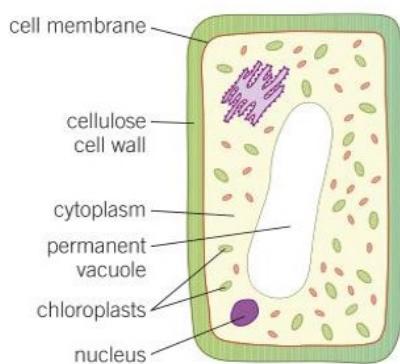


Figure 2 A photosynthetic plant cell

### Synoptic link

You will learn much more about photosynthesis in Chapter B8.

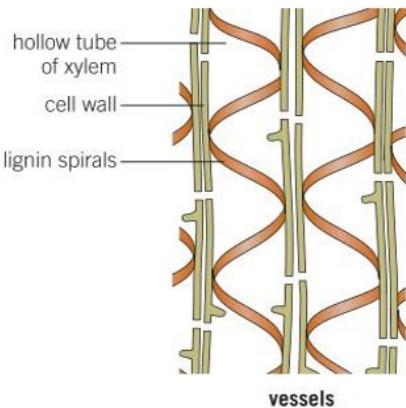
### Xylem cells

**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.

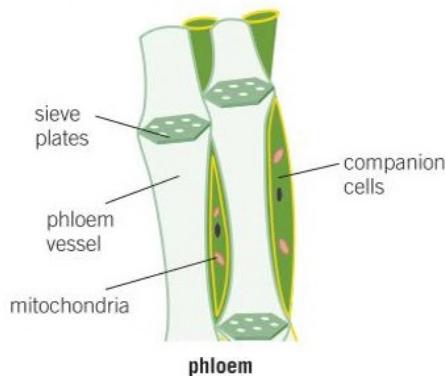


**Figure 3** The adaptations of xylem cells

## 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.

- Name one adaptation for each of the following specialised plant cells. Describe how this adaptation helps the cell carry out its function:
  - root hair cell [2 marks]
  - xylem cell [2 marks]
  - phloem cell [2 marks]
  - photosynthetic cell [2 marks]
- Suggest why a cell within the trunk of a tree cannot carry out photosynthesis. [2 marks]
- Describe the features you would look for to decide on the function of an unknown specialised plant cell. [6 marks]

## Synoptic link

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



## Key points

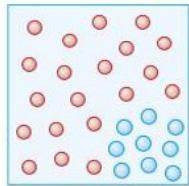
- Plant cells may be specialised to carry out a particular function.
- Examples of specialised plant cells are root hair cells, photosynthetic cells, xylem cells, and phloem cells
- Plant cells may be specialised to function within tissues, organs, organ systems, or whole organisms.

# B1.6 Diffusion

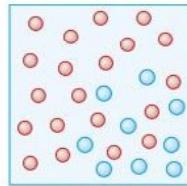
## Learning objectives

After this topic, you should know:

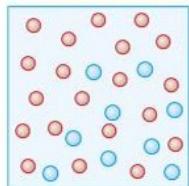
- how diffusion takes place and why it is important in living organisms
- what affects the rate of diffusion.



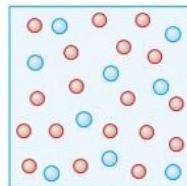
At the moment when the blue particles are added to the red particles they are not mixed at all



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

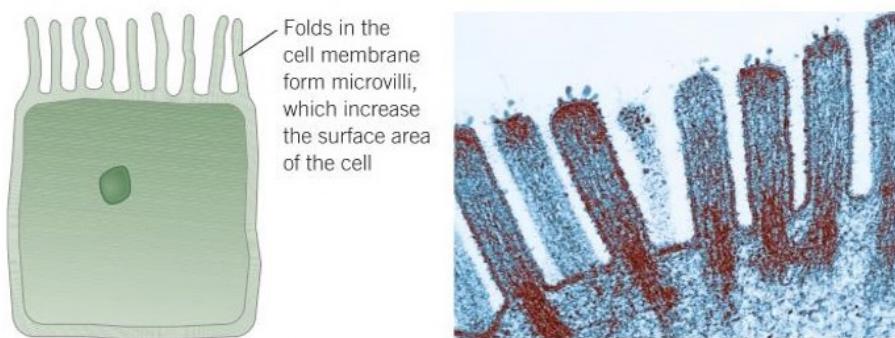
Dissolved substances move into and out of your cells by diffusion across the cell membrane. These include simple sugars, such as glucose, gases

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  $\times 57\,600$

- 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**.

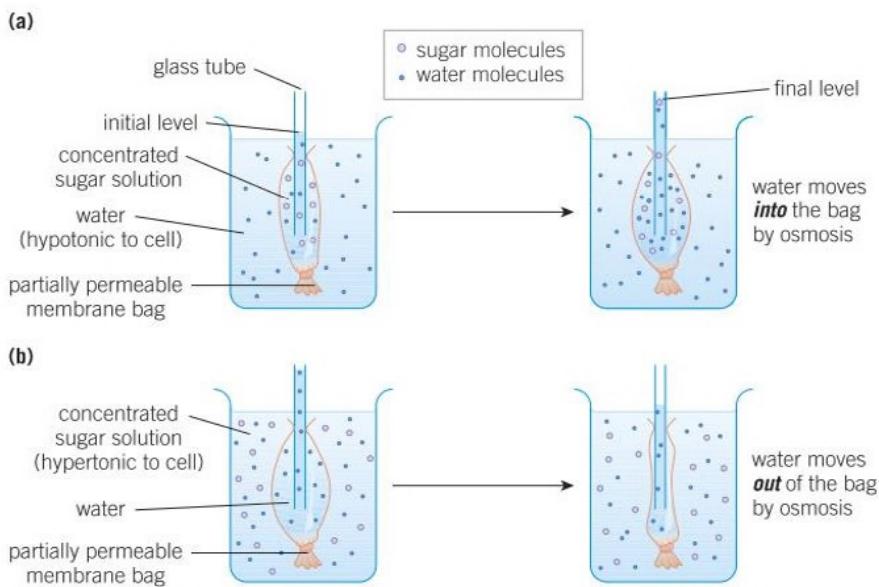
### How osmosis differs from diffusion

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).

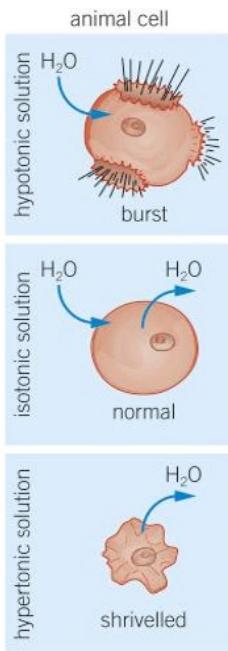
- If the concentration of solutes in the solution outside the cell is **the same** as the internal concentration, the solution is **isotonic** to the cell.
- If the concentration of solutes in the solution outside the cell is **higher** than the internal concentration, the solution is **hypertonic**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

- 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]
- 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]
- 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.

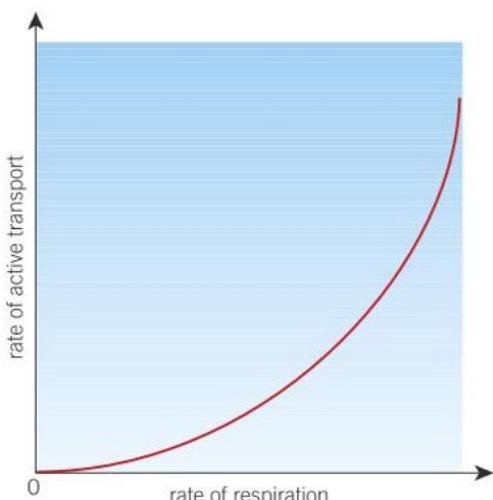
Energy is needed for the active transport system to carry a molecule across the membrane and then return to its original position. This energy is produced during cell respiration. Scientists have shown in a number of different cells that the rate of respiration and the rate of active transport are closely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

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

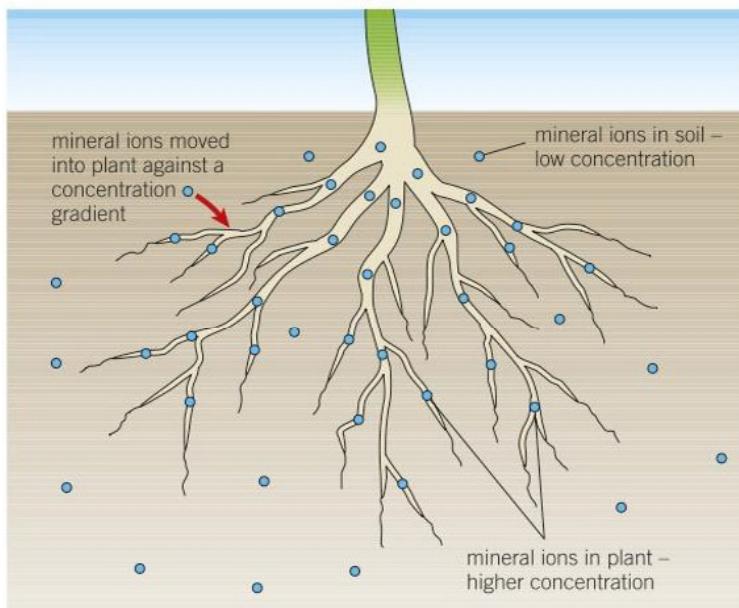
Active transport is widely used in cells. There are some situations where it is particularly important. For example, mineral ions in the soil, such as nitrate ions, are usually found in very dilute solutions. These solutions are more dilute than the solution within the plant root hair cells. By using 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.



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

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.

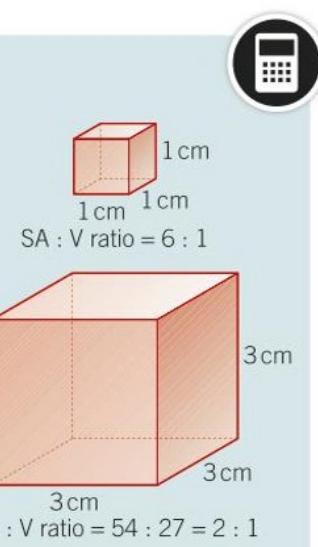


Figure 1 Relationship of surface area to volume

## 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.

## Examples of adaptations

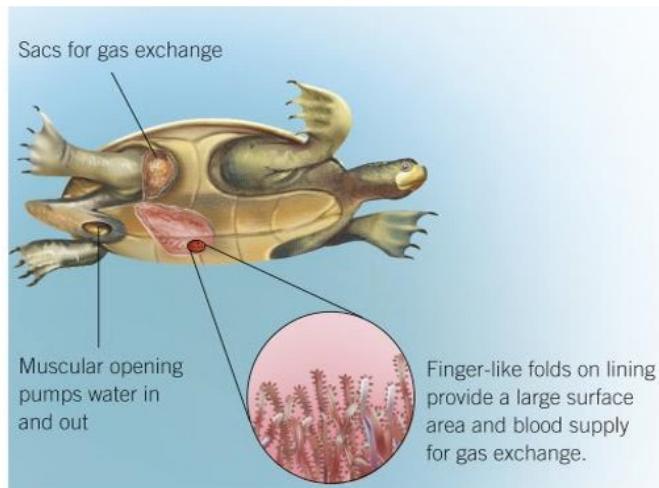
Different organisms have very different adaptations for the exchange of materials. For example, the Australian Fitzroy river turtle (locally known as the bum-breathing turtle) can 'breathe' underwater (Figure 2). Inside the rear opening are two large sacs lined with finger-like folds which provide a 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.



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

## 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]

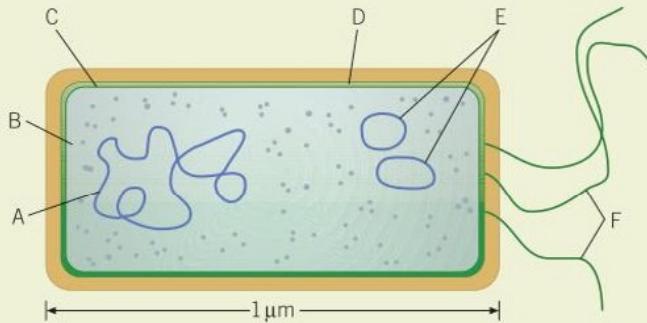


Figure 1

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]

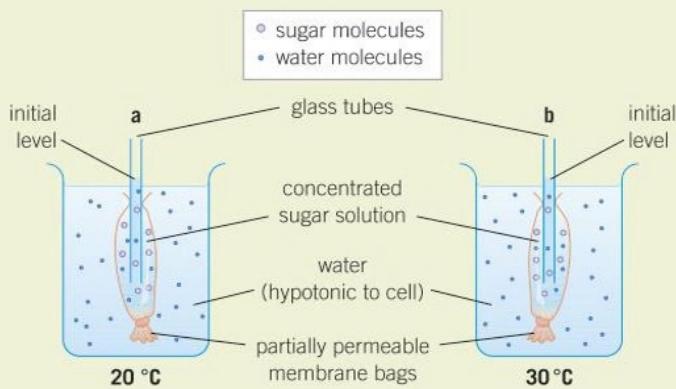


Figure 2

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.

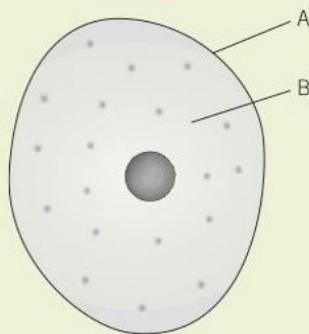
a Give two different adaptations that are found in living organisms to make this more efficient. [2 marks]

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

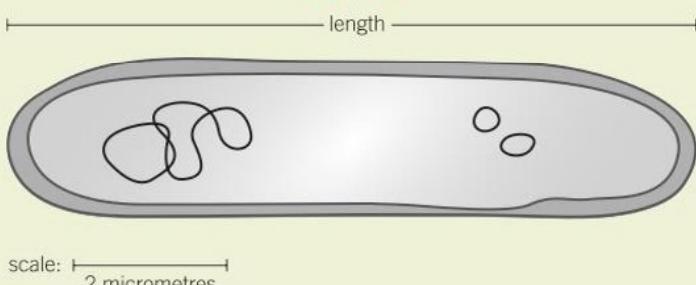
[1 mark]

**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]

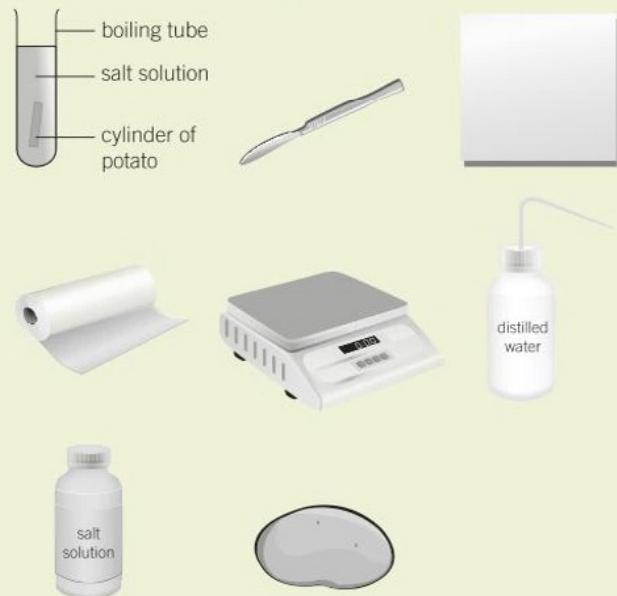
**02.3** Bacterial cells are prokaryotic cells.

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.



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.

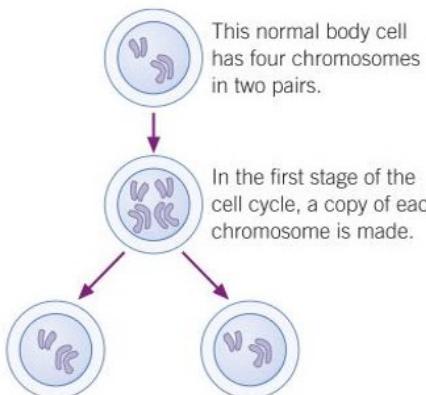
### The cell cycle

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.



The cell divides in two to form two daughter cells, each with a nucleus containing four chromosomes identical to the ones in the original parent cell.

**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:

- chromosome
- gene
- DNA.

[1 mark]

[1 mark]

[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]

- 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  $3.7 \times 10^{13}$  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 ( $3.72 \times 10^{13}$ ) 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.

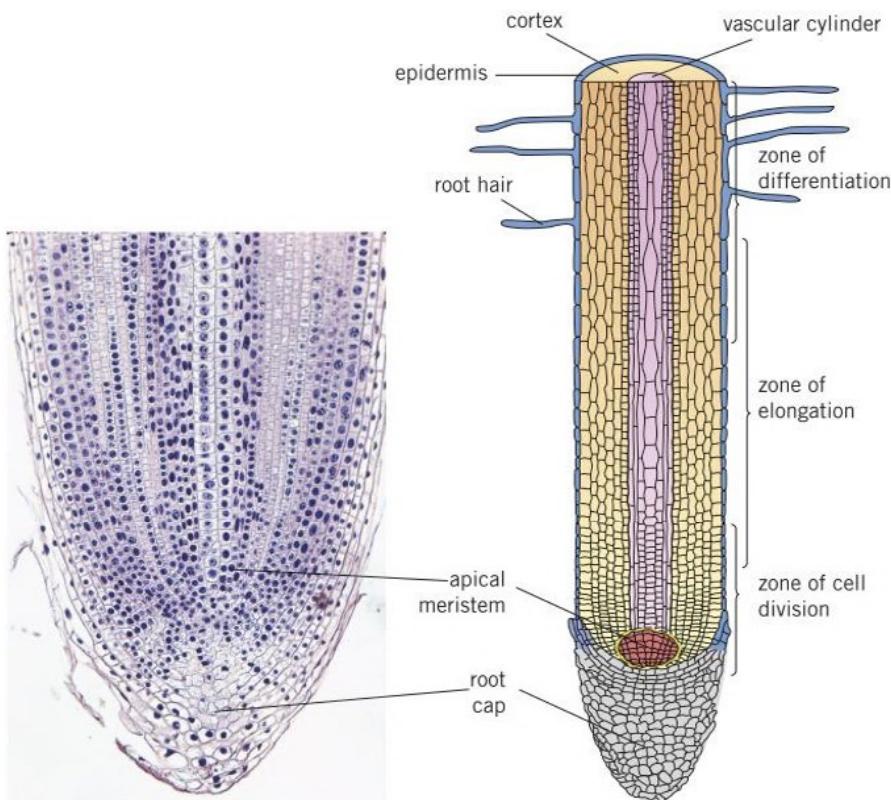
Most specialised cells can divide by mitosis, but they can only form the same sort of cell. Muscle cells divide to produce more muscle cells, for example. Some differentiated cells, such as red blood cells and skin cells, cannot divide at all and so **adult stem cells** replace dead or damaged cells. 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 plant 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.

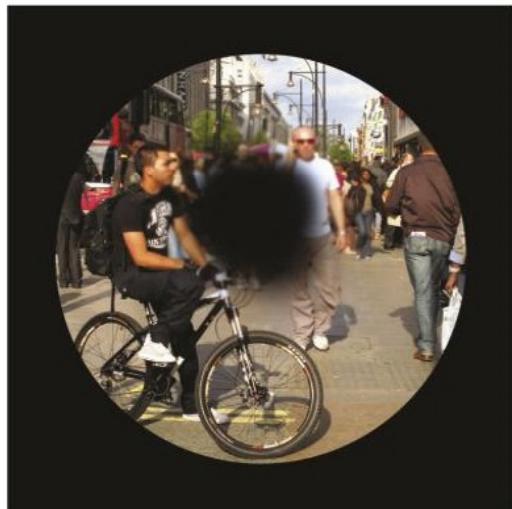
Many of your differentiated cells can divide to replace themselves. However, some tissues cannot do this and stem cells can stay in these tissues for years, only needed if the cells are injured or affected by disease. Then they start dividing to replace the different types of damaged cell.

## 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.

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.



**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

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).

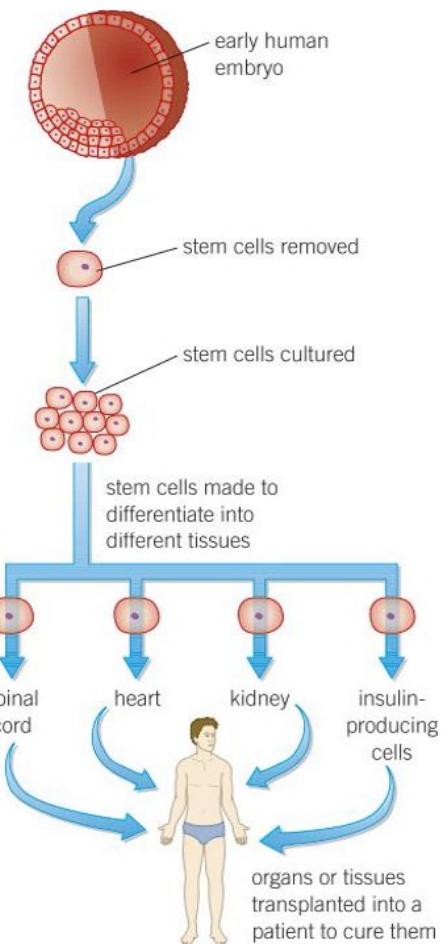
The area of stem cell research known as **therapeutic cloning** (Figure 2) has much potential but is proving very difficult. It involves using cells from an adult to produce a cloned early embryo of themselves. This would provide a source of perfectly matched embryonic stem cells. In theory, these could 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

### 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.

- 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]

# 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 a 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.

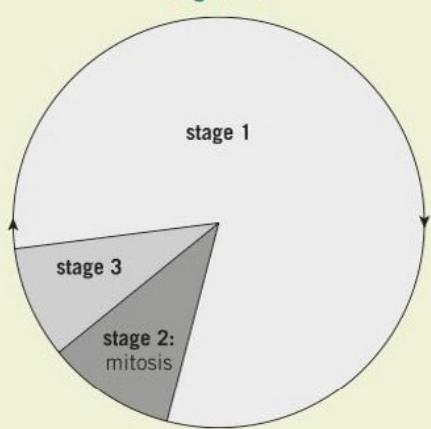
**02.1** How many new daughter cells are formed when one of these cells divides by mitosis. [1 mark]

**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.

### 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).

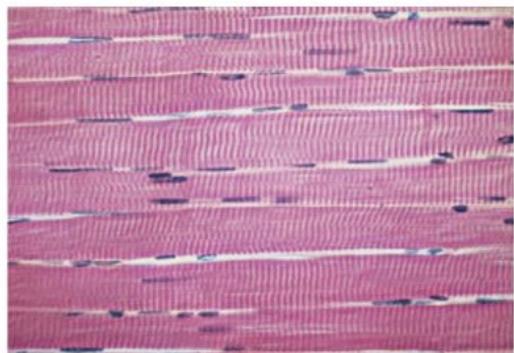


Figure 1 Muscle tissue contracts to move your skeleton around – magnification  $\times 4$

### Synoptic links

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

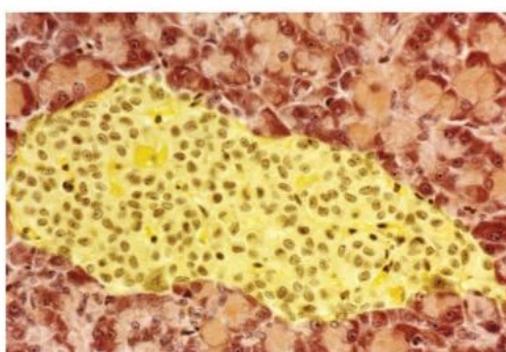
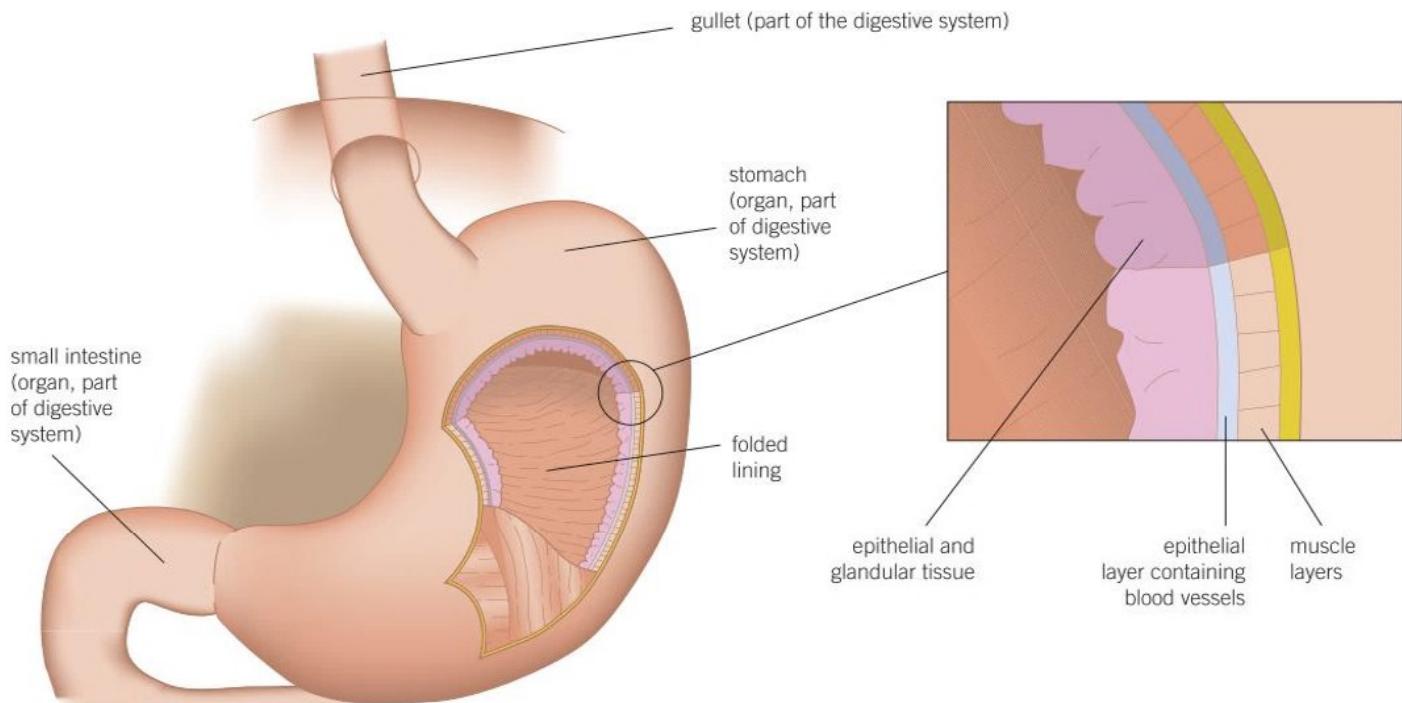


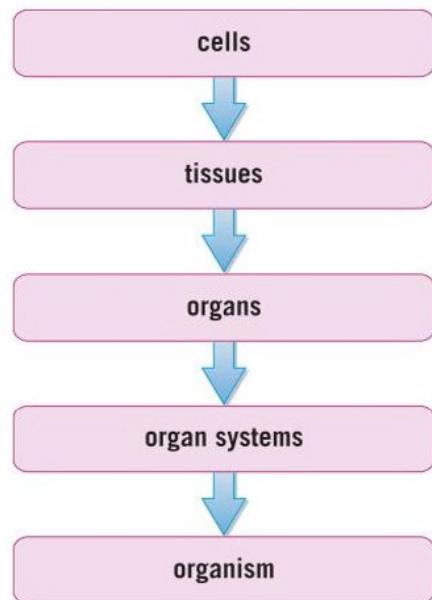
Figure 2 The pancreas showing the tissue that makes hormones (stained yellow) and the tissue that makes enzymes (stained red) – magnification  $\times 1250$



**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.

## 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:

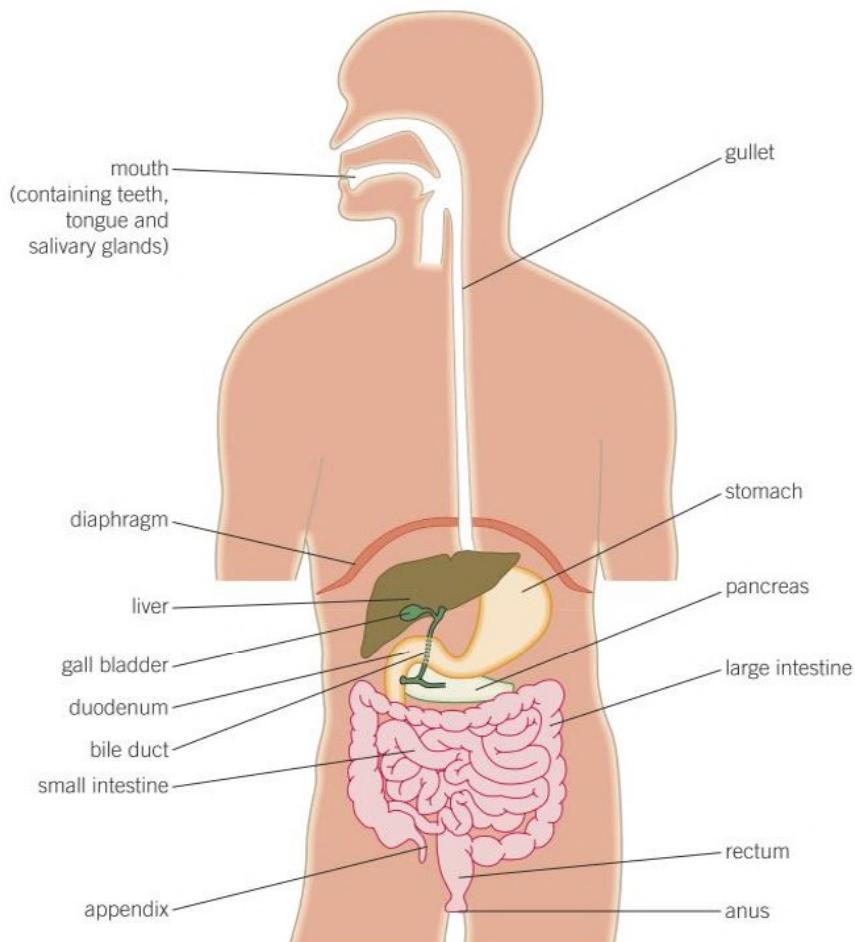
- the position of the main organs of the human digestive system.

## 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

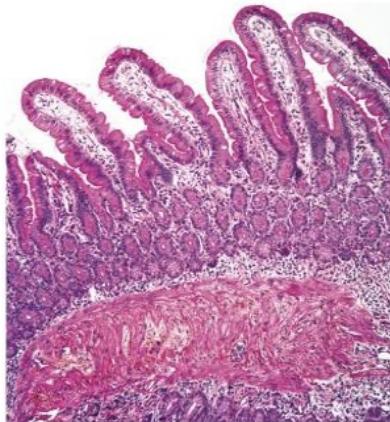
Your digestive system is between 6 and 9 m long – 9 million times or 6 orders of magnitude longer than an average human cell! The digestive system of humans and other mammals exchanges substances with the environment. The food you take in and eat is made up of large insoluble molecules. Your body cannot 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.



**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  $\times 70$

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]

## Synoptic links

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



## 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.

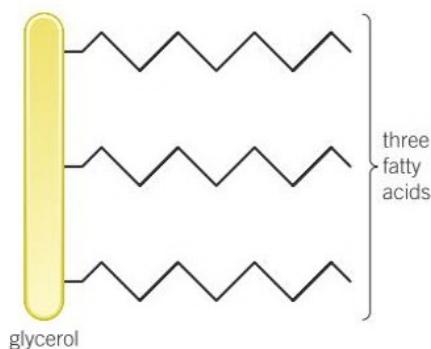


Figure 2 Lipids are made of three molecules of fatty acids joined to a molecule of glycerol

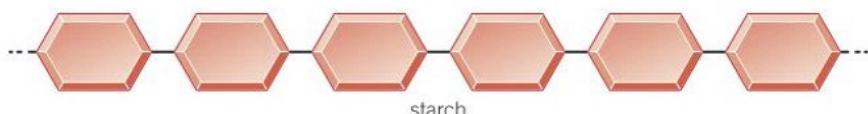
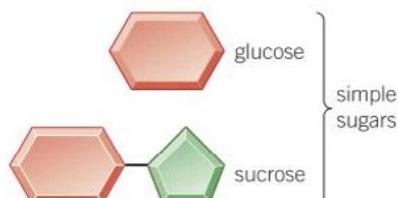


Figure 1 Carbohydrates are all based on simple sugar units

### 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.

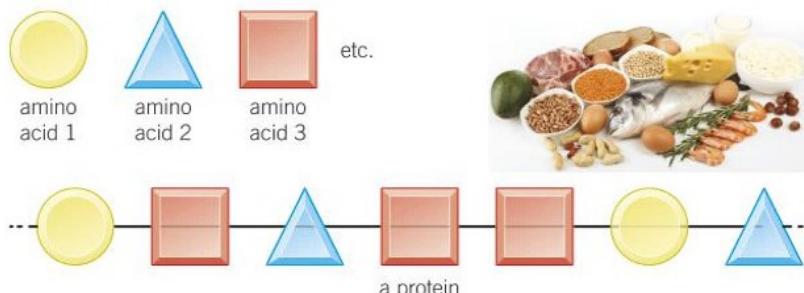
Lipids are made up of three molecules of **fatty acids** joined to a molecule of **glycerol** (Figure 2). The glycerol is always the same, but the fatty acids

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.

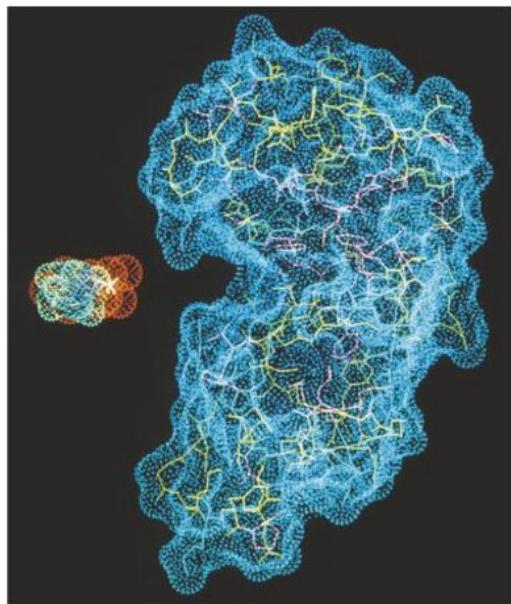


# B3.4 Catalysts and enzymes

## 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.



**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

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.

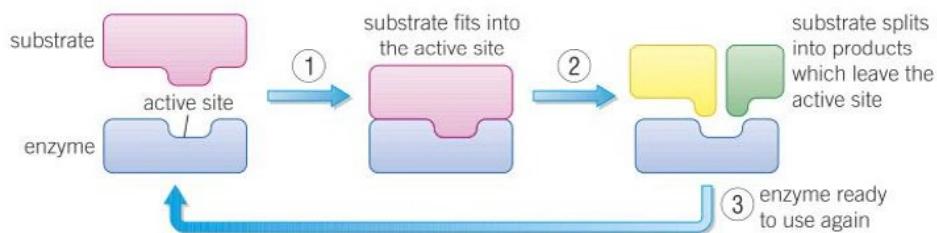
## Enzymes – biological catalysts

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.

### 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:

- manganese(IV) oxide (an inorganic catalyst) and
- 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 catalyst [1 mark]

b an enzyme [1 mark]

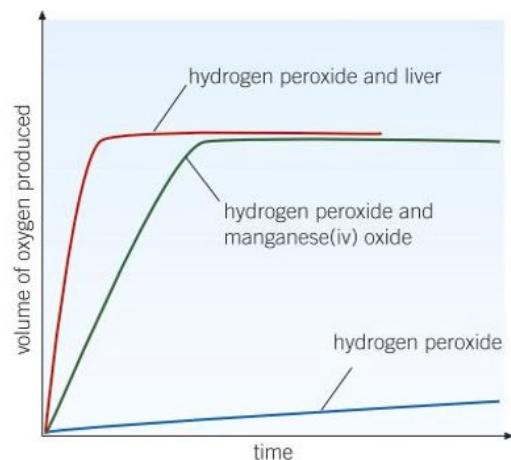
c the active site of an enzyme. [1 mark]

- 2 a Describe what enzymes are made of.

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]



**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

### 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.

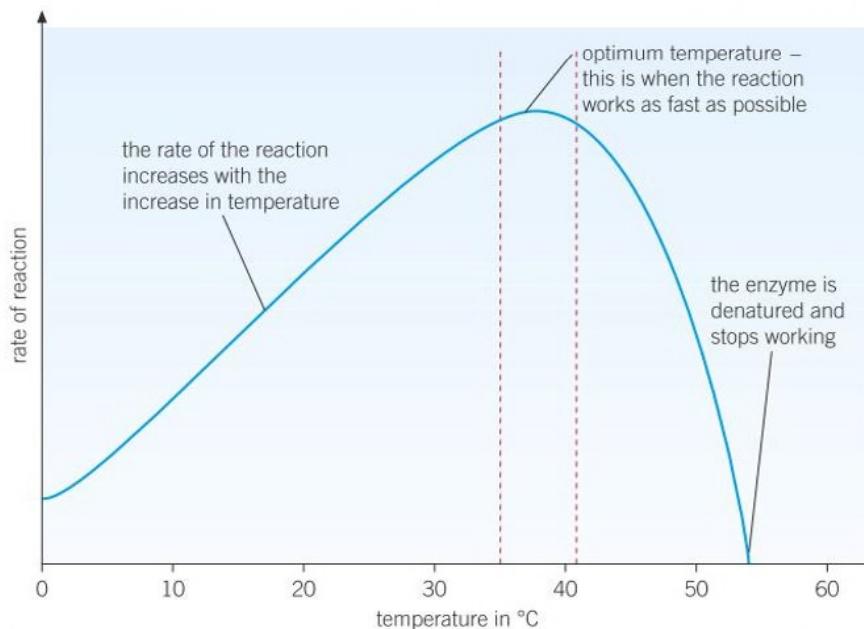
Biological reactions are affected by the same factors as any other chemical reactions. These factors include concentration, temperature, and surface area. However, in living organisms, an increase in temperature only increases the rate of reaction up to a certain point.

## 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.



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

**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

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.

### Study tip

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

### Key points

- 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]

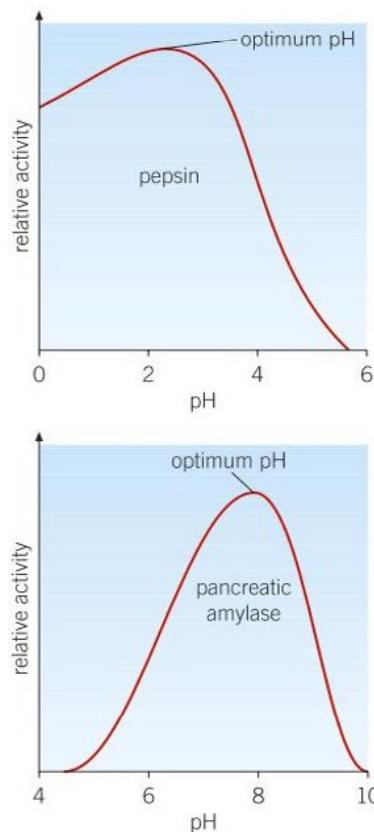
- Enzyme activity is affected by temperature and pH.
- High temperatures denature the enzyme, changing the shape of the active site.
- pH can affect the shape of the active site of an enzyme and make it work very efficiently or stop it working.

# 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 it is 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.

## 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

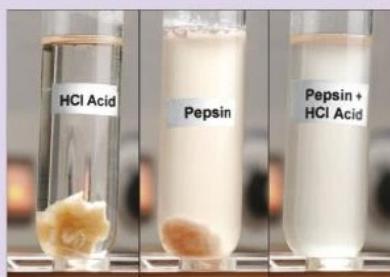
It is very important for the enzymes of the digestive system to have the largest possible surface area of food to work on. This is not a problem with carbohydrates and proteins. However, the fats that you eat do not mix with all the watery liquids in your digestive system. They stay as large globules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

### 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.

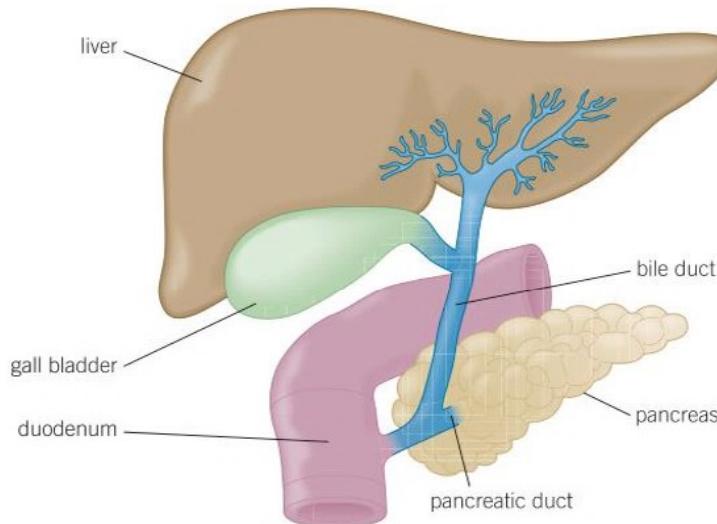
- What conclusions can you make?



**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.

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

- Name the conditions needed for the protease enzyme pepsin from the stomach to work best. [1 mark]
- Describe how your body creates the right pH in the stomach for this enzyme. [2 marks]
- Describe in what conditions the proteases in the small intestine work best. [1 mark]
- 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]

- 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.

# B3 Organisation and the digestive system

## Summary questions

1

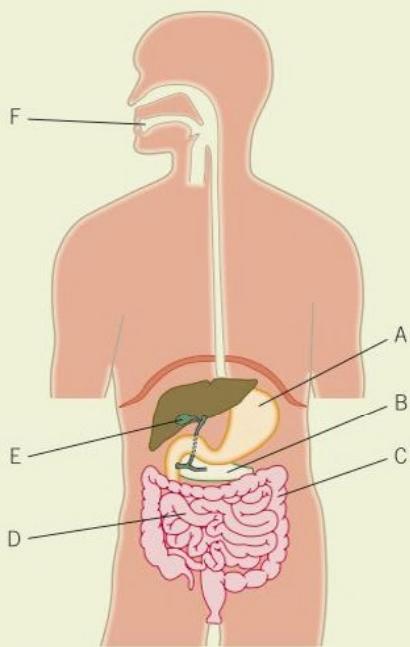


Figure 1

- 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

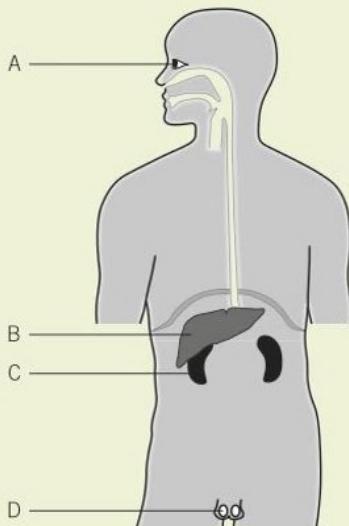
The basic building block of living organisms is called .....

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]

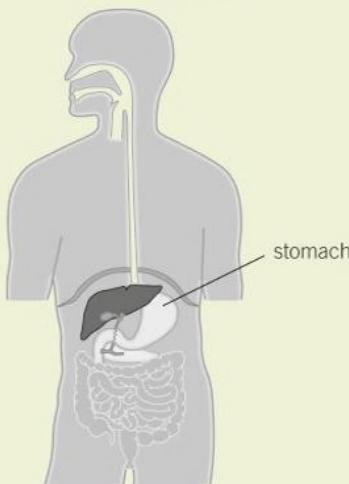
**02.2** Which organ is part of the nervous system? [1 mark]

**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.

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

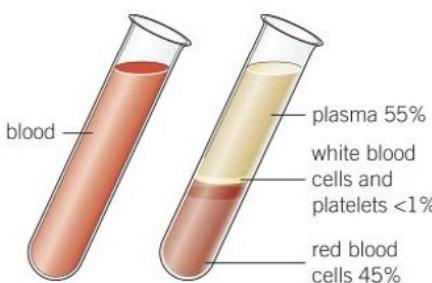
Your blood plasma is a yellow liquid. The plasma transports all of your blood cells and some other substances around your body.

- 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.

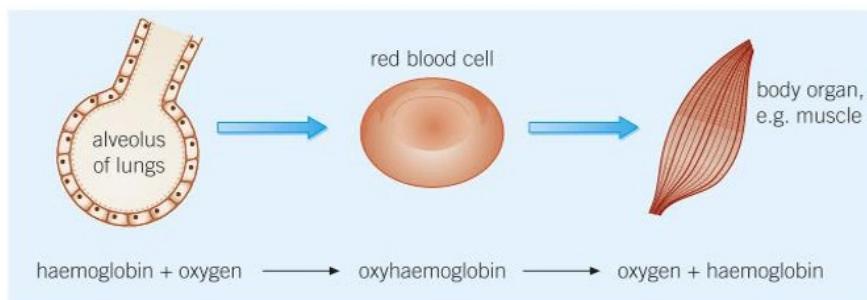
### Red blood cells

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



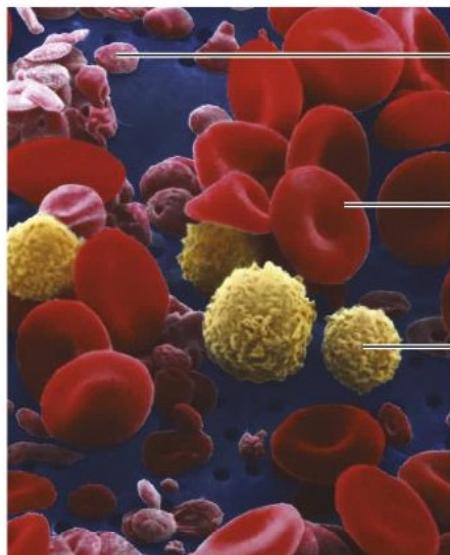
**Figure 2** The reversible reaction between oxygen and haemoglobin makes life as we know it possible by carrying oxygen to all the places where it is needed

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



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

- 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.

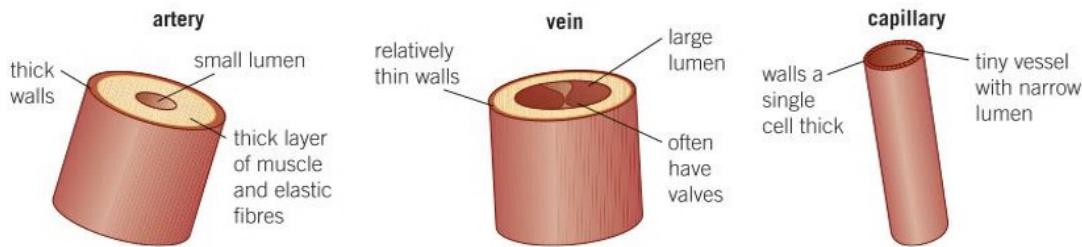
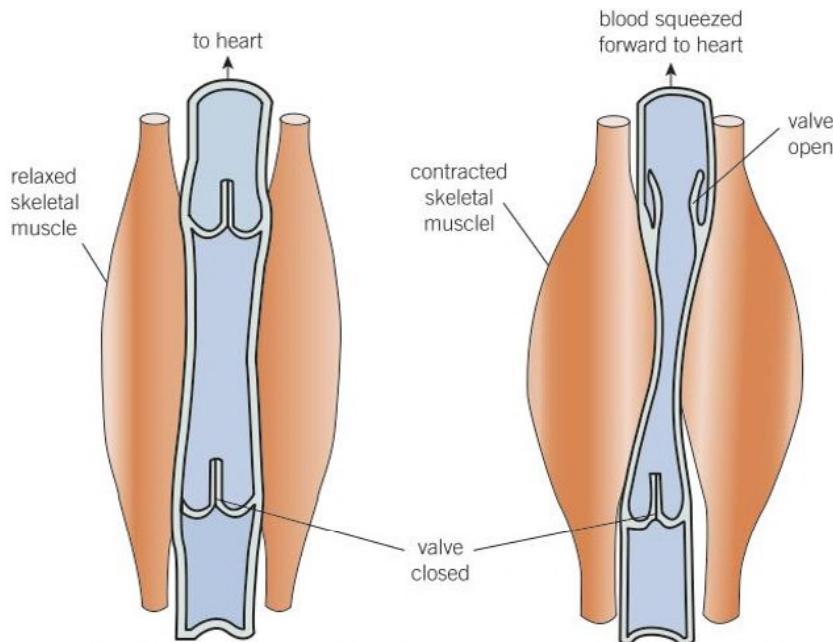


Figure 1 The three main types of blood vessels



**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.

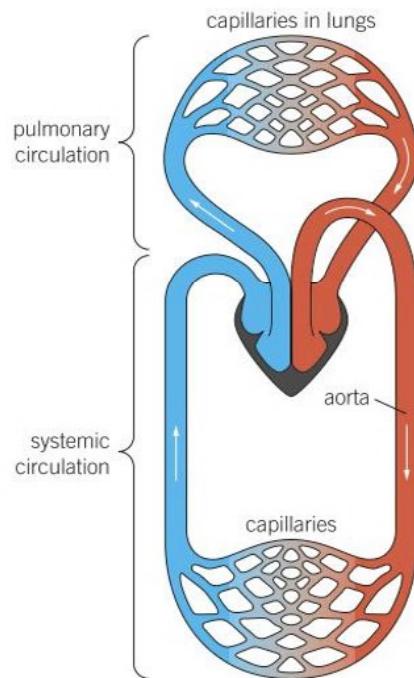
## Double circulation

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.

- Name the function of each of the following blood vessels. Describe how the structure of the blood vessel relates to its function.
  - arteries [3 marks]
  - veins [3 marks]
  - capillaries. [2 marks]
- a Describe how the heart, arteries, veins, and capillaries are linked together in the circulatory system. [2 marks]
  - Describe what happens in capillaries in a cell. [2 marks]
- 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.

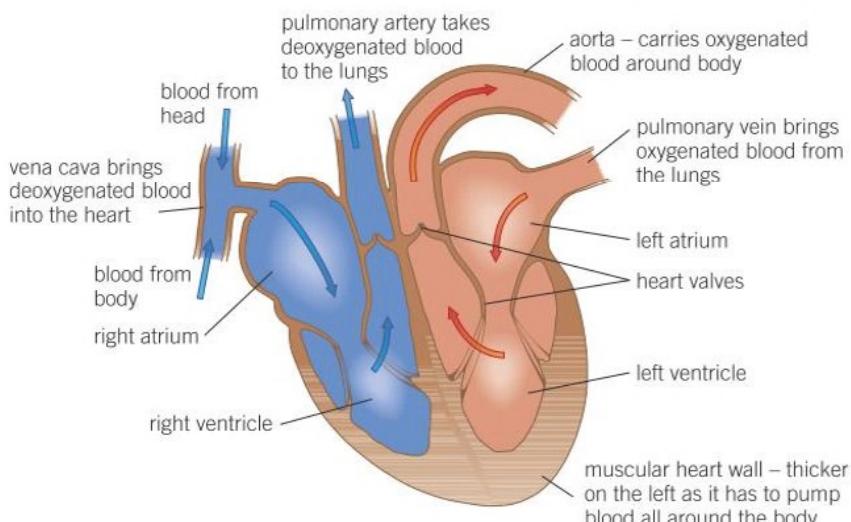
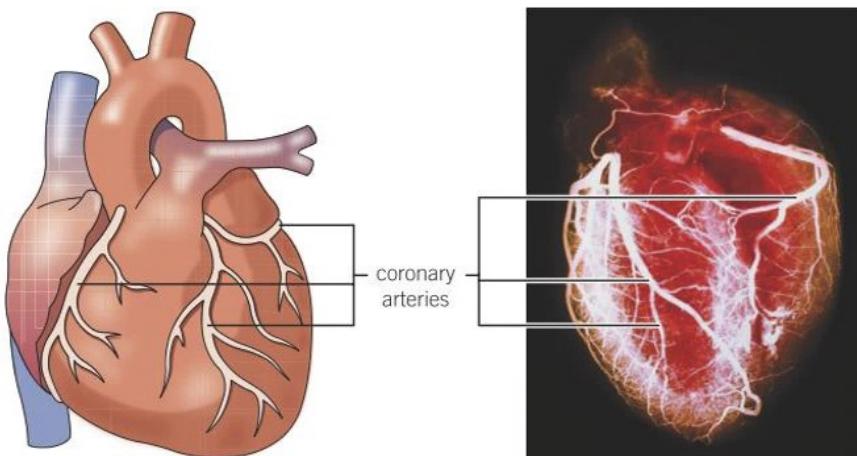


Figure 1 The structure of the heart

## 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

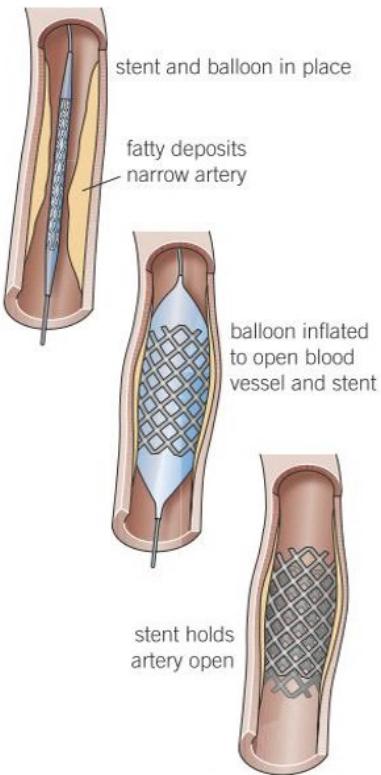
Doctors often solve the problem of coronary heart disease with a **stent**. A stent is a metal mesh that is placed in the artery. A tiny balloon is inflated to open up the blood vessel and the stent at the same time. The balloon is deflated and removed but the stent remains in place, holding the blood 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

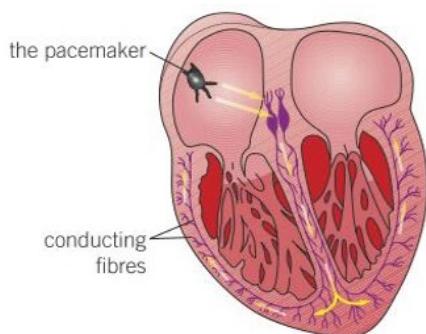
- The heart is an organ that pumps blood around the body.
- Heart valves keep the blood flowing in the right direction.
- Stents can be used to keep narrowed or blocked arteries open.
- Statins reduce cholesterol levels in the blood, reducing the risk of coronary heart disease.

# 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

## 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.

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

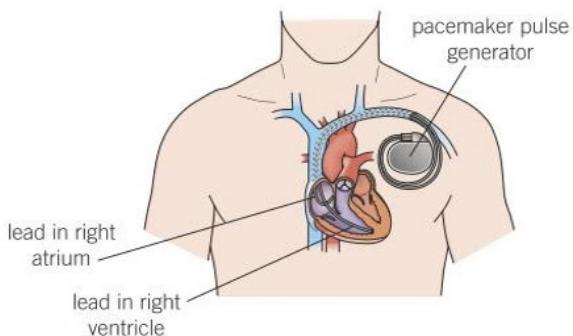
Heart valves have to withstand a lot of pressure. Over time they may start to leak or become stiff and not open fully, making the heart less efficient. People affected may become breathless and without treatment, will eventually die.

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.



**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.

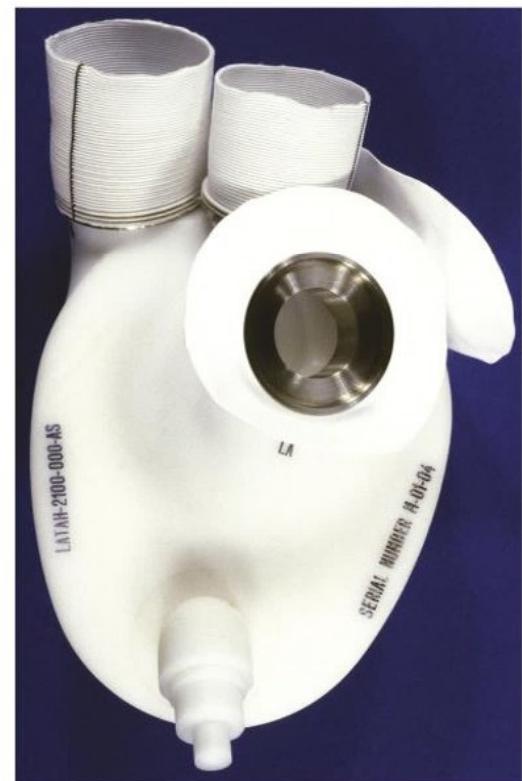
## Artificial hearts

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

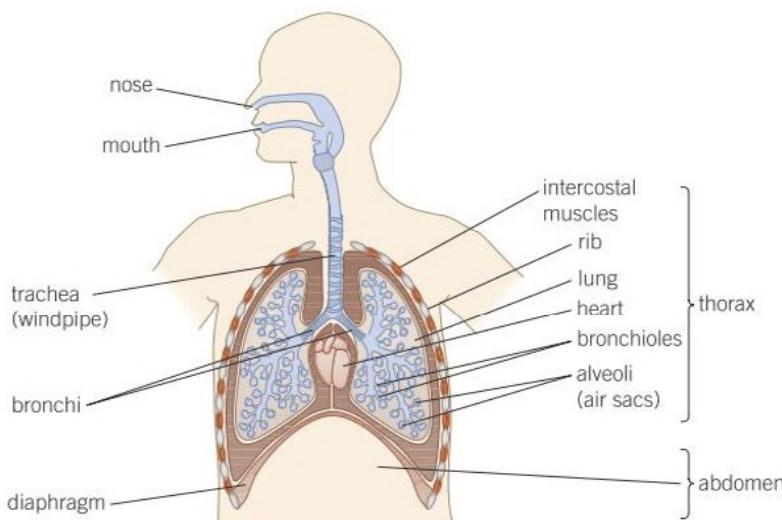
After this topic, you should know:

- 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

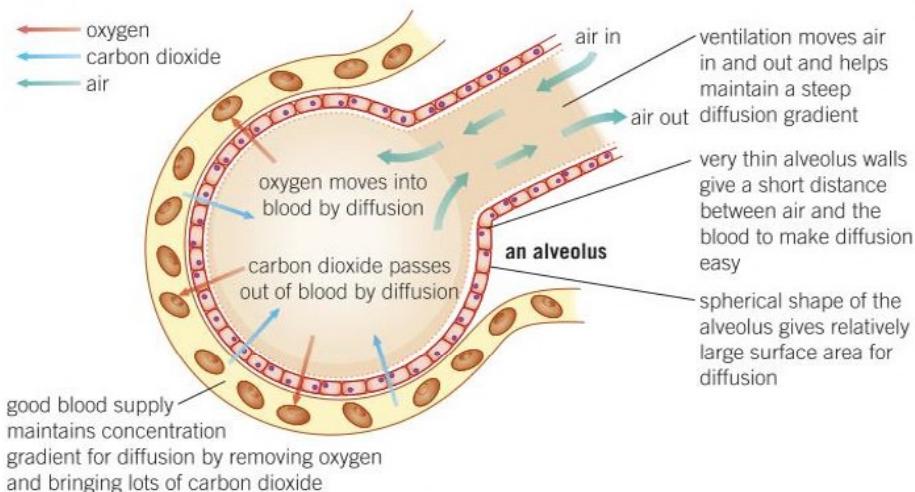
**Table 1** The composition of inhaled and exhaled air (~ means approximately)

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.



**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  
b Explain why it is so important in your body. [1 mark]  
[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).  
b People often say we breathe in oxygen and breathe out carbon dioxide. Use your bar chart to explain why this is wrong. [3 marks]  
c Describe the adaptations of the human gas exchange system and explain how they make it as efficient as possible. [6 marks]

## Synoptic links

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



## 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.

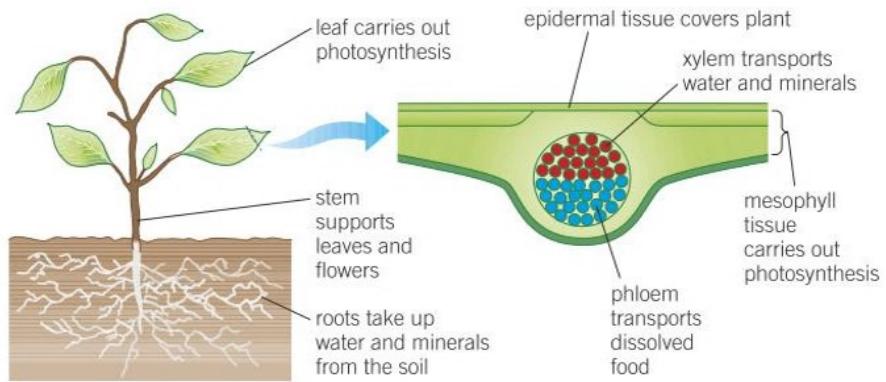
## Plant tissues

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

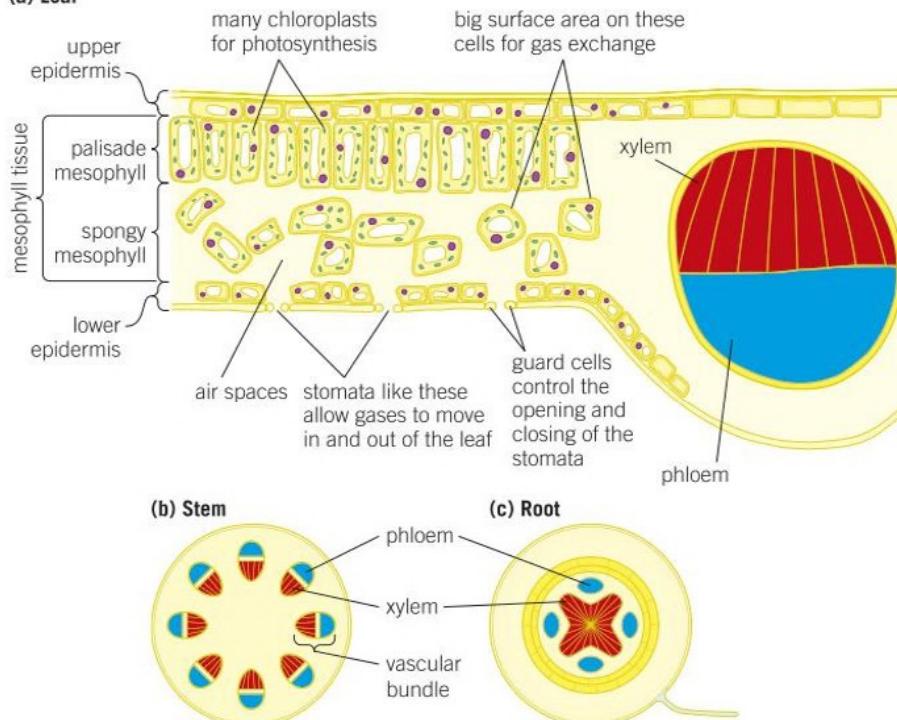
Within the body of a plant, specialised tissues such as palisade, spongy mesophyll, xylem, and phloem are arranged to form organs. Each organ carries out its own particular functions. The leaves, stems, and roots are all plant organs, each of which has a very specific job to do (Figure 2).



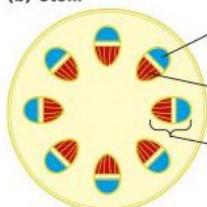
**Figure 2** Some of the main plant organs

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

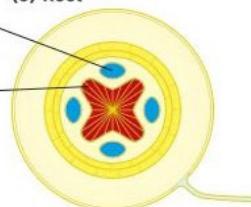
**(a) Leaf**



**(b) Stem**



**(c) Root**



**Figure 3** Plants have specialised 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  $100\text{ }\mu\text{m}$  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.



## Key points

- Plants contain specialised tissues that are adapted to their function. Explain how:
  - epidermal tissues protect the surface of the leaf [1 mark]
  - palisade mesophyll tissue is adapted for photosynthesis [1 mark]
  - spongy mesophyll tissue is adapted for photosynthesis. [1 mark]
- Explain how the tissues in a leaf are arranged to form an effective organ for photosynthesis. [6 marks]

- 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.

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.



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

#### 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.

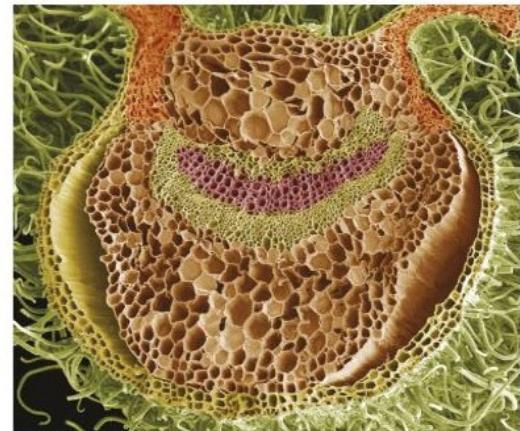


**Figure 2** Without protective collars on the trunks, deer would destroy the transport tissue of young trees like these and kill them before they could become established in the woodland

## 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.



**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.

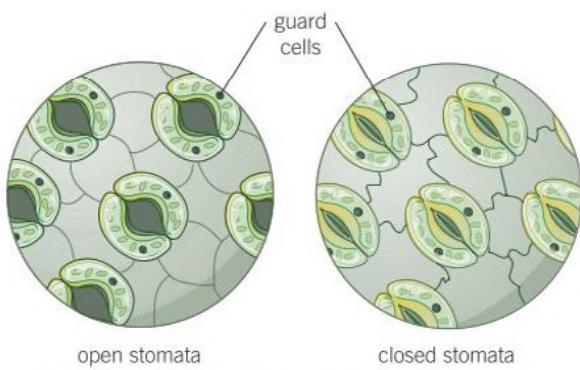
- 1 Explain why a plant needs a transport system. [1 mark]
- 2 Describe the main differences between xylem and phloem in a plant. [3 marks]
- 3 A local woodland trust has set up a scheme to put protective plastic covers around the trunks of young trees. Some local residents are objecting to this, saying 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]

# B4.8 Evaporation and transpiration

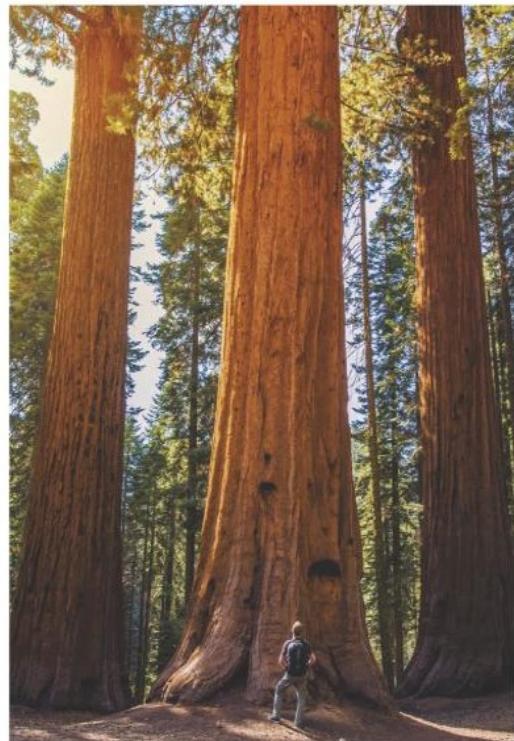
## Learning objectives

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

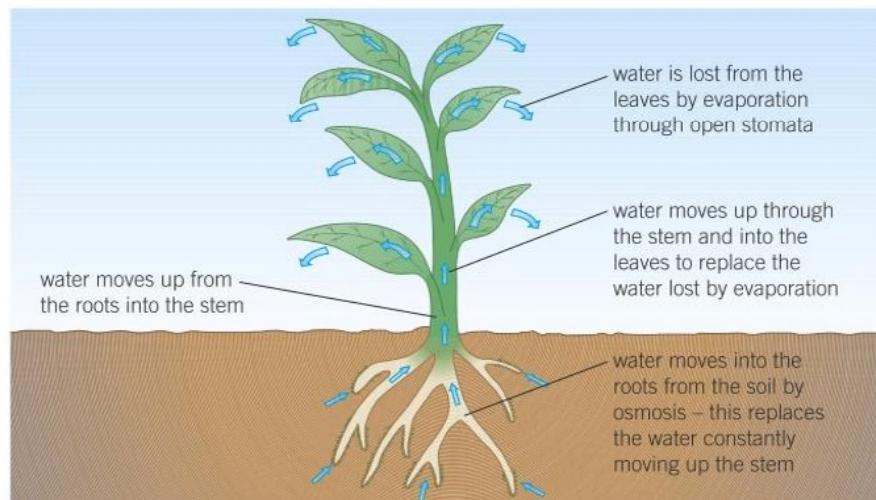
The top of a tree may be many metres from the ground. Yet the leaves at the top need water just as much as those on the lower branches. So how do they get the water they need?

## 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.

## Finding the mean and estimating

When you carry out stomatal counts there are two bits of maths that will be useful – finding the mean and estimating.

**To find the mean:** The mean is the average of the numbers. To find the mean you add together all your data sets and then divide by the number of samples you have taken, for example:

A student looked at the number of stomata on the underside of a leaf. They did five counts and the results per unit area were: 10, 12, 15, 8, 10.

The mean number of stomata per unit area ( $0.1\text{ mm}^2$ )

$$\begin{aligned} &= \frac{10 + 12 + 15 + 8 + 10}{5} \\ &= \frac{55}{5} = 11 \end{aligned}$$

**Sampling:** You will sample the surface area of the leaf by taking peels from randomly selected regions to make your counts. The randomness will be imposed, at least in part, by where the film actually peels successfully from the leaf.

**Estimating:** When you estimate, you are getting a 'ball-park' figure, not a precise measurement. For example, you might work out the mean number of stomata:

- per  $\text{mm}^2$  of a leaf. If you know the size of the field of vision you were using, for example,  $0.1\text{ mm}^2$ , you can get an estimated number of stomata per  $1\text{ mm}^2$ . In this example this is  $11 \times 10 = 110$
- per leaf. You can work out the approximate area of the entire leaf using graph paper. If, for example, the leaf has an area of  $5\text{ cm}^2$ , the estimated number of stomata would be  $11 \times 500 = 5500$  stomata per leaf.

You can find out more about finding the mean in Maths skills M2b, sampling in Maths skills M2d, and estimating numbers in Maths skills M2h.



## Investigating stomata

Stomata are key to the control of transpiration. There are a number of different ways you can investigate the numbers and distribution of stomata on a leaf. You can compare the upper and lower sides of a leaf, different areas of the same leaf surface, different leaves from the same plant, and different types of leaves. The main steps are:

- 1 Making a stomatal peel – use nail varnish or a water-based varnish to cover an area of the leaf and then peel it off.
- 2 Place the peel on a microscope slide.
- 3 With an eyepiece graticule, use a low magnification and count the number of stomata in a random sample of squares.
- 4 Without an eyepiece graticule, use a higher magnification and count the number of stomata in the field of vision and repeat this with a number of sample areas of the peel to collect your data.
- 5 You can calculate the mean number of stomata on a given area of a leaf.
- 6 You can use this to estimate the number of stomata on the whole leaf.



## Study tip

Remember that the transpiration stream is driven by the loss of water by evaporation out of the stomata.

1 a	What are stomata?	[1 mark]
b	Describe their role in the plant.	[2 marks]
2	Describe the process of transpiration.	[3 marks]
3	Explain how water moves up a plant in the transpiration stream.	[3 marks]
4	A student measured the numbers of stomata per $\text{mm}^2$ of leaf surface. Their counts were: 250, 280, 265, 245, 270, 255, 290. Calculate the mean number of stomata (to 3 significant figures).	[3 marks]

## Key points

- The loss of water vapour from the surface of plant leaves is known as transpiration.
- Water is lost through the stomata, which open to let in carbon dioxide for photosynthesis.
- The stomata and guard cells control gas exchange and water loss.

# B4.9 Factors affecting transpiration

## Learning objectives

After this topic, you should know:

- the factors that affect the rate of transpiration
- ways of investigating the effect of environmental factors on rates of water uptake.



**Figure 1** Dry air and high temperatures make it very hard for leafy plants to survive as they lose so much water through transpiration

## The effect of the environment on transpiration

Different conditions affect the rate of transpiration – as a result, some environments are much tougher for plants to survive in than others.

Factors that affect the rate of transpiration include temperature, humidity, the amount of air movement, and light intensity.

Anything that increases the rate of photosynthesis will increase the rate of transpiration, because more stomata open up to let in carbon dioxide. When stomata are open, the rate at which water is lost by evaporation and diffusion increases. Therefore, an increase in light intensity will increase the rate of transpiration.

Conditions that increase the rate of evaporation from the leaf cells and diffusion of water from open stomata will also make transpiration happen more rapidly. Hot, dry, windy conditions increase the rate of transpiration because more water evaporates from the cells and diffusion happens quicker. Water vapour diffuses more rapidly into dry air than into humid air because the concentration gradient is steeper. Windy conditions both increase the rate of evaporation and also maintain a steep concentration gradient from the inside of the leaf to the outside by removing water vapour as it diffuses out.

Temperature affects the rate of transpiration in several ways. The molecules move faster as the temperature increases, so diffusion occurs more rapidly. The rate of photosynthesis also increases as the temperature goes up, so more stomata will be open for gas exchange to take place. Each of these conditions individually increases the rate of transpiration and, when combined, a plant will lose a lot of water in this way.

## Controlling water loss

Many plants have adaptations that help them to photosynthesise as much as possible while losing as little water as possible.

Most leaves have a waxy, waterproof layer (the cuticle) to prevent uncontrolled water loss. In very hot environments, the cuticle may be very thick and shiny. Most of the stomata are found on the underside of the leaves. This protects them from the direct light and energy of the Sun.

If a plant begins to lose water faster than it is replaced by the roots, it can result in some drastic measures.

- The whole plant may wilt. Wilting is a protection mechanism against further water loss. The leaves all collapse and hang down. This greatly reduces the surface area available for water loss by evaporation.
- Stomata close, which stops photosynthesis and risks overheating. However, this prevents most water loss and any further wilting.

The plant will remain wilted until the temperature drops, the sun goes in, or it rains.

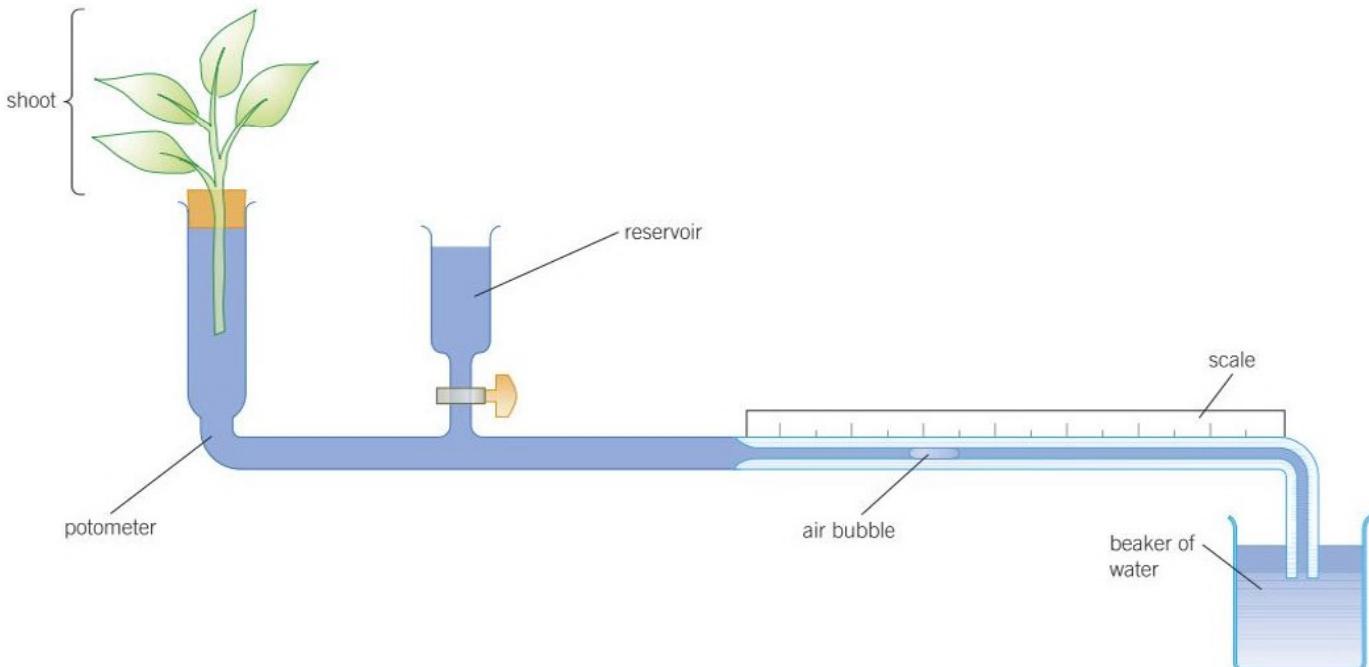
## Measuring transpiration rates

There are many ways to investigate the effect of different factors on the rate of transpiration in plants. Many of them involve a piece of apparatus known as a potometer.

A potometer can be used to show how the uptake of water by a plant changes in different conditions. This gives you a good idea of the amount of water lost by the plant in transpiration. Almost all of the water taken up by a plant is lost in transpiration, but a small amount is used in the metabolism, for example, in photosynthesis.

### Synoptic link

You will learn more about plant adaptations to reduce transpiration in harsh environments in Topic B16.8.



**Figure 2** A potometer is used to show the water uptake of a plant under different conditions

- 1 **a** Name the parts of the leaf that help the plant to reduce water loss under normal conditions. [2 marks]
- b** Explain the effect on transpiration of a fan blowing onto the leaves of the plant. [4 marks]
- 2 **a** Describe the effect on plant transpiration of coating the top surface of the leaves in petroleum jelly. [1 mark]
- b** Describe the effect on plant transpiration of coating the bottom surface of the leaves in petroleum jelly. [1 mark]
- c** Explain the difference in the responses you have described for parts **a** and **b**. [3 marks]
- 3 Water lilies have their stomata on the tops of their leaves.
  - a** Suggest why this is an important adaptation for water lilies [2 marks]
  - b** Controlling transpiration is not very important to water lilies. Suggest reasons for this. [2 marks]

### Key points

- Factors that increase the rate of photosynthesis or increase stomatal opening will increase the rate of transpiration. These factors include temperature, humidity, air flow, and light intensity.
- Transpiration is more rapid in hot, dry, windy, or bright conditions.

# B4 Organising animals and plants

## Summary questions

1 Here are descriptions of three heart problems. In each case, use what you know about the heart and the circulatory system to explain the problems caused by the condition.

a The valve that stops blood flowing back into the left ventricle of the heart after it has been pumped into the aorta becomes weak and floppy and begins to leak. [4 marks]

b Some babies are born with a 'hole in the heart' – there is a gap in the central dividing wall of the heart. They may look blue in colour and be listless. [4 marks]

c The coronary arteries supplying blood to the heart muscle itself may become clogged with fatty material. The person affected may get chest pain when they exercise or even have a heart attack. [4 marks]

2 In each of the following examples, explain the effect on the blood and what this means to the person involved:

a an athlete gives blood before running a race [4 marks]  
b someone eats a diet low in iron. [4 marks]

3 If a patient has a blocked blood vessel, doctors may be able to open up the blocked vessel with a stent or replace it with bits of healthy blood vessels taken from other parts of the patient's body.

Figure 1 shows you the results of these procedures in one group of patients after one year.

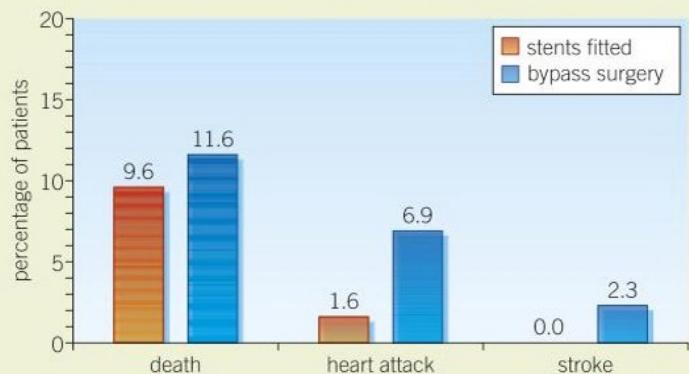


Figure 1

a Describe a stent and explain how it works. [3 marks]

b Determine, based on the evidence in Figure 1, which technique seems to be most successful for treating blocked coronary arteries. Explain your decision. [3 marks]

4 a Describe how the lungs are adapted to allow the exchange of oxygen and carbon dioxide between the air and the blood. [3 marks]

b Describe how air is moved in and out of the lungs and explain how this ventilation of the lungs makes gas exchange more efficient. [4 marks]

5 Plants have specialised cells, tissues, and organs, just as animals do.

a Give **three** examples of plant tissues. [3 marks]

b Roots, stems, and leaves are important plant organs. Describe how the structure of each is adapted to its functions. [6 marks]

c Explain which plant tissues are common to all of the main plant organs. [2 marks]

6 The apparatus in Figure 2 (known as a potometer) is often used to give an approximate measure of the transpiration taking place in a plant.

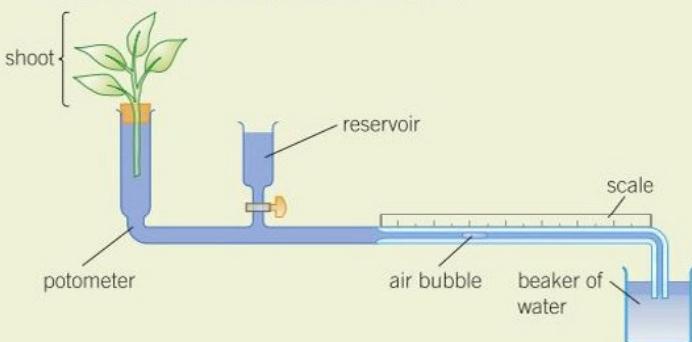


Figure 2

a Define the term transpiration. [2 marks]

b Explain carefully what a potometer measures and why it does *not* measure transpiration. [3 marks]

c Readings are taken using a potometer with plants in different conditions. Explain how and why you would expect the readings to vary from the normal control shoot if:

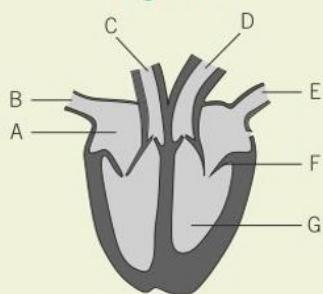
i a fan was set up to blow air over the plant [3 marks]

ii the underside of all the leaves was covered with petroleum jelly. [3 marks]

## Practice questions

**01** **Figure 1** shows a diagram of the heart.

**Figure 1**



**01.1** Use the correct letter from **Figure 1** to identify each of the following parts of the heart.

left ventricle
a valve
vena cava
vessel carrying blood containing the most oxygen

[4 marks]

**01.2** What is the function of a valve? [1 mark]

**01.3** The coronary arteries carry blood to the heart muscle cells.

In coronary heart disease layers of fatty material build up inside the coronary arteries.

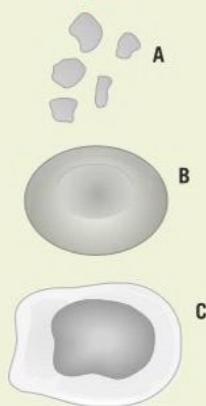
Explain why this could be dangerous. [3 marks]

**01.4** People who are at risk of developing coronary heart disease are often given drugs called statins.

Describe how statins reduce the risk of coronary heart disease. [2 marks]

**02** **Figure 2** shows the components of the blood.

**Figure 2**

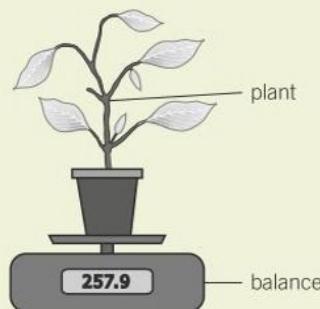


**02.1** Name components **A**, **B**, and **C**. [3 marks]

**02.2** Describe **three** ways that red blood cells are adapted to transport oxygen from the lungs to cells of the body. [3 marks]

**03** A student investigated the loss of water from a plant. **Figure 3** shows the apparatus he used.

**Figure 3**



**03.1** What is the loss of water through the leaves of a plant called? [1 mark]

The student measured the mass of the plant and pot at the end of each day for five days.

His results are shown in **Table 1**.

**Table 1**

Day	Mass of pot and plant in g
0	257.9
1	253.6
2	248.8
3	238.9
4	235.4
5	231.9

**03.2** During which day did the plant lose the most water? Suggest a reason for this. [2 marks]

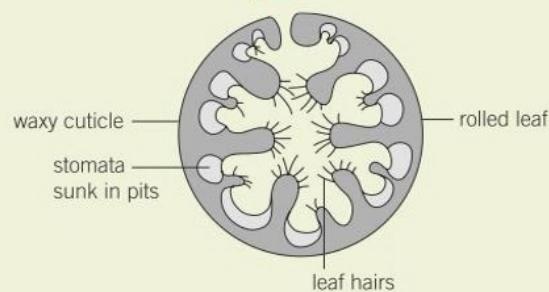
**03.3** Calculate the mean rate of water loss in g/day.

Give your answer to 2 significant figures. [3 marks]

Marram grass grows on sand dunes where the conditions are dry and windy. The leaves are adapted to reduce the rate of water loss.

**Figure 4** shows a cross section of a marram grass leaf.

**Figure 4**



**03.4** Describe how **two** features of the marram grass leaf help to reduce the rate of water loss. [2 marks]

# 2

# Disease and bioenergetics

Communicable diseases are caused by pathogens – microorganisms that can be spread from one organism to another. In this section you will learn how we defend ourselves from the pathogens that attack us, and how our lifestyles affect our risk of developing non-communicable diseases such as heart disease and cancer.

You will also learn about photosynthesis in plants – the process where they use light to make sugar from carbon dioxide and water. You will also look at respiration – all living organisms use respiration to transfer the energy they need to carry out the reactions required for life.

## Key questions

- What are communicable diseases and how can we prevent them?
- How can your lifestyle affect your risk of developing many non-communicable diseases?
- How do plants use the glucose they make during photosynthesis?
- What is the difference between aerobic and anaerobic respiration?

## Making connections

- You will learn about genetic diseases, which are not infectious but can be passed from parents to their offspring, in **B13 Reproduction**
- You will discover the importance of photosynthesis in feeding relationships and ecological communities in **B16 Adaptations, interdependence, and competition** and **B17 Organising an ecosystem**.
- You will find out how pollution of a waterway by fertilisers or sewage can make it impossible for water animals to respire in **B18 Biodiversity and ecosystems**.

## I already know...

## I will learn...

The consequences of imbalances in the diet.

More about the impact of obesity on human health.

The importance of bacteria in the human digestive system.

The role of bacteria and other pathogens in human and plant diseases, and how to calculate the effect of antibacterial chemicals by measuring the area of zones of inhibition.

The impact of exercise and smoking on the human gas exchange system.

How exercise and smoking can affect the health of other systems of the body.

The effects of recreational drugs on behaviour, health, and life processes.

How to interpret data to understand the effect of lifestyle factors including diet, alcohol, and smoking on the incidence of non-communicable diseases at local, national, and global levels.

The basic principles of photosynthesis.

How to measure and calculate the rate of photosynthesis, and how different factors affect the rate of photosynthesis.

The differences between aerobic and anaerobic respiration.

How an oxygen debt builds up during anaerobic respiration in your muscles.

## Required Practicals

Practical	Topic
2 Investigating the effects of antiseptics and antibiotics	B5.4
6 Light intensity and the rate of photosynthesis	B8.2

# 5 Communicable diseases

## 5.1 Health and disease

### Learning objectives

After this topic, you should know:

- what health is
- the different causes of ill health
- how different types of disease interact.

### Synoptic links

Find out more about diseases in Chapter B6 and Chapter B7.



### Synoptic links

You will learn more about cancer in Topic B7.2.



### Synoptic link

For more help in interpreting correlations, look at Maths skills MS2g.

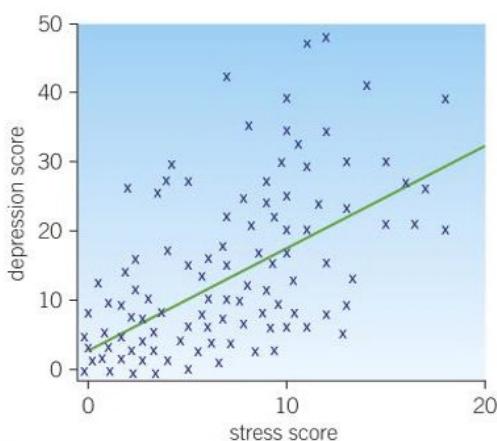


Your health is a state of physical and mental well-being, not just an absence of disease. It is at least partly based on individual perceptions. A cold or headache that might make you feel ill enough to stay in bed on a school day might be less likely to be a problem if you are on holiday.

### What makes us ill?

**Communicable (infectious) diseases** (e.g., tuberculosis and flu) are caused by **pathogens** such as bacteria and viruses that can be passed from one person to another. **Non-communicable diseases** cannot be transmitted from one person to another (e.g., heart disease and arthritis). Both communicable and non-communicable diseases are major causes of ill health, but other factors can also affect health. Here are three examples:

- Diet – if you do not get enough to eat, or the right nutrients, you may suffer from diseases ranging from starvation to anaemia or rickets. Too much food, or the wrong type of food, can lead to problems such as obesity, some cancers, or type 2 diabetes.
- Stress – a certain level of stress is inevitable in everyone's life and is probably needed for our bodies to function properly. However, scientists are increasingly linking too much stress to an increased risk of developing a wide range of health problems. These include heart disease, certain cancers, and mental health problems.
- Life situations – these include:
  - the part of the world where you live
  - your gender
  - your financial status
  - your ethnic group
  - the levels of free health care provided where you live
  - how many children you have
  - local sewage and rubbish disposal.



**Figure 1** Scatter graphs can show a correlation between stress and depression

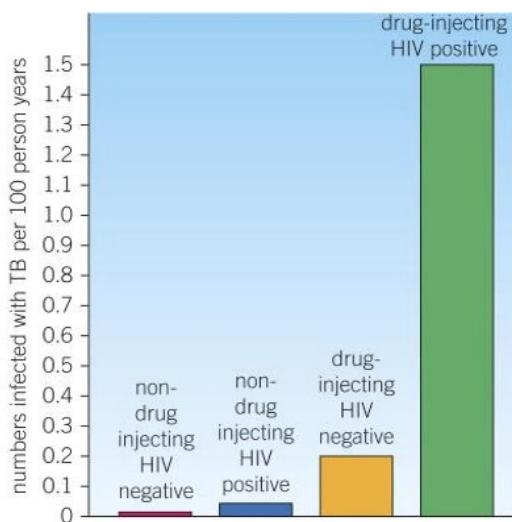
People often have little or no control over their life situation, especially as children or young people. Yet such factors have a big effect on health and well-being and are responsible for many causes of ill health around the world. These include communicable diseases such as diarrhoeal diseases and malaria, through to non-communicable diseases such as heart disease and cancer.

## How health problems interact

In the next three chapters you will be looking at different types of diseases in isolation. It is important to remember that in the real world, different diseases and health conditions happen at the same time. They interact and often one problem makes another worse. Here are a number of examples – you will learn more about the details of many of these conditions in later chapters.

- Viruses living in cells can trigger changes that lead to cancers – for example, the human papilloma virus can cause cervical cancer.
- The immune system of your body helps you destroy pathogens and get better. If there are defects in your immune system, it may not work effectively. This may be a result of your genetic makeup, poor nutrition, or infections such as HIV/AIDS. This means you will be more likely to suffer from other communicable diseases (Figure 2).
- Immune reactions initially caused by a pathogen, even something like the common cold, can trigger allergies to factors in the environment. These allergies may cause skin rashes, hives, or asthma.
- Physical and mental health are often closely linked. Severe physical ill health can lead to depression and other mental illness.
- Malnutrition is often linked to health problems including deficiency diseases, a weakened immune system, obesity, cardiovascular diseases, type 2 diabetes, and cancer.

The interaction between different factors, including lifestyle, environment, and pathogens, is an important principle to remember as you look at different types of disease.



**Figure 2** Data collected in the Netherlands looks at the interaction between a number of health problems including HIV status and drug use in the incidence of tuberculosis (TB) in Amsterdam

- 1 Define what is meant by good health. [1 mark]
- 2 a Name three different factors that can cause ill health. [3 marks]
  - b Give an example of ill health that each factor can produce. [3 marks]
- 3 a What health interactions does the data in Figure 2 cover? [2 marks]
  - b What effect does injecting drugs have on your chances of becoming infected with tuberculosis (TB)? [1 mark]
  - c Which group has the greatest chance of getting TB? [1 mark]
  - d How much more likely is it for an injecting drug user who is HIV positive to get tuberculosis than for an injecting drug user who is HIV negative?  
Give your answer to the nearest whole number. [2 marks]
- 4 Explain how the interactions between different types of disease can affect the prevalence of a disease around the World. [6 marks]

### Key points

- Health is a state of physical and mental well-being.
- Diseases, both communicable and non-communicable, are major causes of ill health.
- Other factors including diet, stress, and life situations may have a profound effect on both mental and physical health.
- Different types of diseases may and often do interact.

# B5.2 Pathogens and disease

## Learning objectives

After this topic, you should know:

- what pathogens are
- how they cause disease
- how pathogens are spread.



**Figure 1** Many bacteria are very useful to humans but some, such as this strain of E. coli, are pathogens and cause disease

### Synoptic link

Remind yourself about the structure of bacteria by looking back to Topic B1.3.



**Communicable diseases**, also known as infectious diseases, are found all over the world. Microorganisms that cause disease are called pathogens. Pathogens may be bacteria, viruses, protists, or fungi, and they infect animals and plants, causing a wide range of diseases.

Communicable diseases are caused either directly by a pathogen or by a toxin made by a pathogen. The pathogen can be passed from one infected individual to another individual who does not have the disease. Some communicable diseases are fairly mild, such as the common cold and tonsillitis. Others are known killers, such as tetanus, influenza, and HIV/AIDS.

Sometimes communicable diseases can be passed between different species of organisms. For example, infected animals such as dogs or bats can pass rabies on to people. Tuberculosis can be passed from badgers to cows, and from cows to people.

### What are the differences between bacteria and viruses?

Bacteria and viruses cause the majority of communicable diseases in people. In plants, viruses and fungi are the most common pathogens. Bacteria are single-celled living organisms that are much smaller than animal and plant cells. Bacteria are used to make food such as yogurt and cheese, to treat sewage, and to make medicines. Bacteria are important both in the environment, as decomposers, and in your body. Scientists estimate that most people have between 1 and 2 kg of bacteria in their guts, and they are rapidly discovering that these bacteria have a major effect on our health and well-being.

Pathogenic bacteria are the minority – but they are significant because of the major effects they can have on individuals and society.

**Viruses** are even smaller than bacteria. They usually have regular shapes. Viruses cause diseases in every type of living organism.

### How pathogens cause disease

Once bacteria and viruses are inside your body, they may reproduce rapidly.

- Bacteria divide rapidly by splitting in two (called binary fission). They may produce toxins (poisons) that affect your body and make you feel ill. Sometimes they directly damage your cells.
- Viruses take over the cells of your body. They live and reproduce inside the cells, damaging and destroying them.

Common disease symptoms are a high temperature, headaches, and rashes. These are caused by the way your body responds to the cell damage and toxins produced by the pathogens.

## How pathogens are spread

The more pathogens that get into your body, the more likely it is that you will develop an infectious disease. There are a number of ways in which pathogens spread from one individual to another.

- By air (including droplet infection). Many pathogens including bacteria, viruses, and fungal spores (that cause plant diseases) are carried and spread from one organism to another in the air. In human diseases, droplet infection is common. When you are ill, you expel tiny droplets full of pathogens from your breathing system when you cough, sneeze, or talk (Figure 2). Other people breathe in the droplets, along with the pathogens they contain, so they pick up the infection. Examples include flu (influenza), tuberculosis, and the common cold.
- Direct contact. Some diseases are spread by direct contact of an infected organism with a healthy one. This is common in plant diseases, where a tiny piece of infected plant material left in a field can infect an entire new crop. In people, diseases including sexually transmitted infections, such as syphilis and chlamydia, are spread by direct contact of the skin. Pathogens such as HIV/AIDS or hepatitis enter the body through direct sexual contact, cuts, scratches, and needle punctures that give access to the blood. Animals can act as vectors of both plant and animal diseases by carrying a pathogen between infected and uninfected individuals.
- By water. Fungal spores carried in splashes of water often spread plant diseases. For humans, eating raw, undercooked, or contaminated food, or drinking water containing sewage can spread diseases such as diarrhoeal diseases, cholera, or salmonellosis. The pathogen enters your body through your digestive system.

Lifestyle factors often affect the spread of disease. For example, when people live in crowded conditions with no sewage system, infectious diseases can spread very rapidly.



**Figure 2** Droplets carrying millions of pathogens fly out of your mouth and nose at up to 100 miles an hour when you sneeze

### Synoptic link

For more information on bacteria that are resistant to antibiotics, see Topic B15.8.



### Key points

- |  |  |
|--|--|
| <b>1</b> <b>a</b> What causes infectious diseases? [1 mark]  |  |
| <b>b</b> How do pathogens make you ill? [2 marks]  |  |
| <b>2</b> <b>a</b> Give two ways in which diseases are spread from one person to another. [2 marks]   |  |
| <b>b</b> Give two ways in which diseases are spread from one plant to another. [2 marks]   |  |
| <b>c</b> For each method given in part <b>a</b> and part <b>b</b> , explain how the pathogens are passed from one organism to the other. [4 marks]   |  |
| <b>3</b> Describe and explain the main differences between bacteria and viruses, and how they cause disease.  [6 marks] |  |

- Communicable diseases are caused by microorganisms called pathogens, which include bacteria, viruses, fungi, and protists.
- Bacteria and viruses reproduce rapidly inside your body. Bacteria can produce toxins that make you feel ill.
- Viruses live and reproduce inside your cells, causing cell damage.
- Pathogens can be spread by direct contact, by air, or by water.

# B5.3 Growing bacteria in the lab

## Learning objectives

After this topic, you should know:

- that bacteria multiply by simple cell division
- how to grow an uncontaminated culture of bacteria in the lab
- how uncontaminated cultures are used
- why bacteria are cultured at lower temperatures in schools than in industry.

## Synoptic links

You learnt about mitosis, the process behind binary fission in Topic B2.1.

To find out more about microorganisms, scientists need to culture them. This means they are grown in very large numbers so that scientists can see all of the bacteria (the colony) as a whole. Scientists can find out what nutrients they need to grow and investigate which chemicals are best at killing them. Bacteria are the most commonly cultured microorganisms. They divide rapidly and easily by simple cell division (**binary fission**).

## Growing microorganisms in the lab

To culture (grow) microorganisms, you must provide them with everything they need. This means giving them a liquid or gel containing nutrients – a **culture medium**. This contains carbohydrate as an energy source, various minerals, a nitrogen source so they can make proteins, and sometimes other chemicals. Most microorganisms also need warmth and oxygen to grow.

Hot **agar gel** is poured into a Petri dish. It is then left to cool and set, before you add the microorganisms. You can also culture microorganisms in a flask of sterile nutrient broth solution.

You need uncontaminated cultures of microorganisms to investigate the effects of chemicals such as disinfectants and antibiotics. Contamination can come from your skin, the air, the soil, or the water around you. It is important to avoid any unnecessary contamination. You must take great care when you are culturing microorganisms. The bacteria you want to grow may be harmless. However, there is always the risk that a **mutation** (a change in the DNA) will take place and produce a new and dangerous pathogen.



**Figure 1** When working with the most dangerous pathogens, scientists need to be very careful. Sensible safety precautions are always needed when working with microorganisms

## Study tip

It is important to sterilise solutions and equipment to kill the bacteria already on them. Otherwise they would grow and contaminate the culture to be studied.

### Growing useful organisms

You can prepare an uncontaminated culture of microorganisms in the laboratory on sterile agar plates by following a number of steps.

#### Step 1:

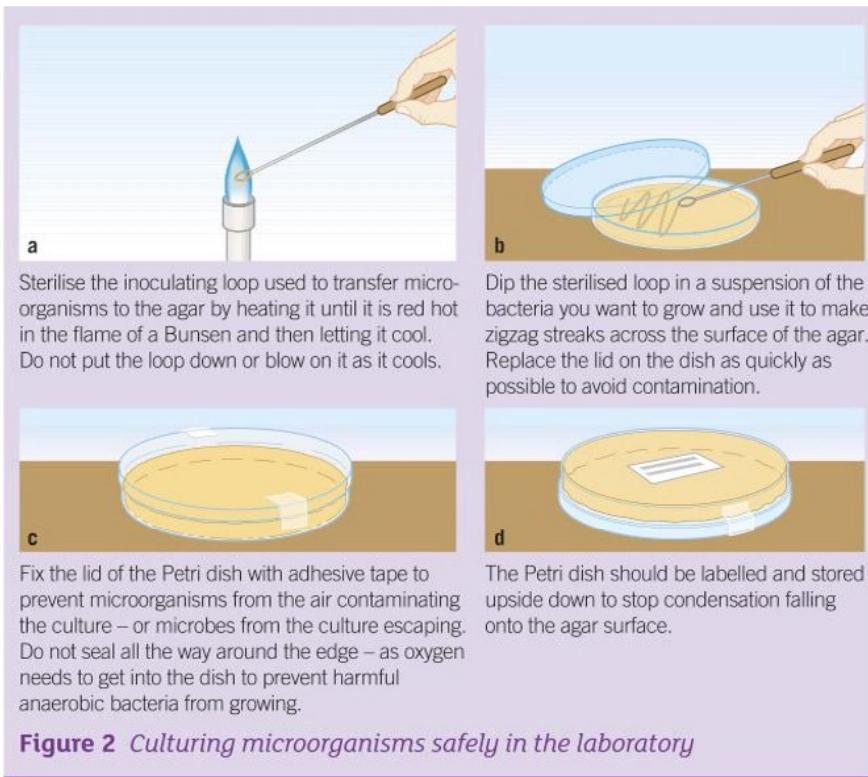
The Petri dishes on which you will grow your microorganisms must be sterilised before use. The nutrient agar must also be sterilised to kill off any unwanted microorganisms. Glass dishes can be sterilised by heating. A special oven called an autoclave is often used. It sterilises using steam at high pressure. Plastic Petri dishes are often bought ready-sterilised. UV light or gamma radiation is used to kill the bacteria.

#### Step 2:

The next step is to **inoculate** the sterile agar with the microorganisms you want to grow (Figure 2).

#### Step 3:

Once you have inoculated your plates, the secured Petri dishes need to be incubated (kept warm) for several days so the microorganisms can grow (Figure 3). Petri dishes should be stored upside down so condensation does not fall from the lid onto the agar surface.



**Figure 2** Culturing microorganisms safely in the laboratory

In school and college laboratories, the maximum temperature at which cultures are incubated is 25 °C. You are surrounded by disease-causing bacteria all the time. If you cultured bacteria at 37 °C (human body temperature), there would be a high risk of growing some dangerous pathogens. If you use a lower temperature, you reduce the likelihood of growing pathogens that might be harmful to people. In industrial conditions, bacterial cultures are often grown at higher temperatures to enable the microorganisms to grow more rapidly – for example, insulin-producing genetically modified (GM) bacteria. A hospital lab also incubates human pathogens at 37 °C, so that they grow as fast as possible and are identified sooner.

- 1 a** Why do scientists culture microorganisms in the laboratory? [2 marks]
- b** Explain why agar gel is important in setting up bacterial cultures. [2 marks]
- 2 a** Suggest why bacteria are grown at 25 °C or below in the school lab when this is not their optimum temperature for growth. [1 mark]
- b** Explain why Petri dishes are not opened before incubation once they have been inoculated and sealed. [2 marks]
- c** Explain why bacteria are often cultured at much higher temperatures in industrial plants and hospital laboratories. [3 marks]
- 3** When you set up a culture of bacteria in a Petri dish you give the bacteria everything they need to grow as fast as possible. However, these ideal conditions do not last forever. Suggest what might limit the growth of the bacteria in a culture on a Petri dish. [6 marks]



**Figure 3** The colonies of microorganisms that grew from a sneeze

### Key points

- An uncontaminated culture of microorganisms can be grown using sterilised Petri dishes and agar. You sterilise the inoculating loop before use and fix the lid of the Petri dish to prevent unwanted microorganisms getting in.
- Uncontaminated cultures of microorganisms are needed for investigating the action of disinfectants and antibiotics.
- Cultures should be incubated at a maximum temperature of 25 °C in schools and colleges to reduce the likelihood of pathogens growing that might be harmful to humans.

# B5.4 Preventing bacterial growth

## Learning objectives

After this topic, you should know:

- that bacteria can divide by binary fission every 20 minutes if they have the right conditions
- how to calculate the number of bacteria in a population
- the effect of disinfectants and antibiotics on bacterial growth.



**Figure 1** There are many different disinfectants that all claim to rid our homes of the microorganisms that cause diseases

## Synoptic links

You will find out more about how we can prevent the spread of disease in Chapter B6.



**Figure 2** Culturing microorganisms makes it possible for us to observe and measure how different chemicals affect them

Bacteria reproduce by simple binary fission – they split in two. If bacteria have the right conditions, including enough nutrients and a suitable temperature, they can grow very fast, dividing every 20 minutes.

## Calculating bacterial growth

The growth rate of a bacteria population is affected by many different factors including temperature, available nutrients, oxygen levels, and pH. Changing any of these factors can affect the growth rate of a population.

You can calculate the number of bacteria in a population after a given time as long as you know the mean division time. This varies greatly, from 15–20 minutes to hours, days, or even years. For example, if you have one bacterium with a mean division time of 20 minutes, in 24 hours you would have  $4722366482869645213696$  ( $4.7 \times 10^{21}$ , to 2 significant figures) bacteria. If the mean division time is 24 hours, you would have just 2!



### Calculating the number of bacteria in a population

The mean division time for a population of bacteria is 30 minutes. Calculate how many bacteria will result from each individual bacterium after 8 hours.

#### Step 1: Calculate how many times the bacteria will divide in 8 hours

If the bacteria divide every 30 minutes they will divide  $\frac{60}{30}$  or two times every hour.

If the colony grows for 8 hours, each of the initial bacteria will divide  $8 \times 2$  or 16 times.

#### Step 2: Calculating the number of bacteria in the population

Every time the bacteria divide, the population doubles, so we can find the number of bacteria using the following equation:

$$\text{bacteria at the end of the growth period} = \text{bacteria at the beginning of the growth period} \times 2^{\text{number of divisions}}$$

In this case:

$$\text{number of bacteria at beginning} = 1$$

$$\text{number of divisions} = 16$$

$$\begin{aligned} \text{number of bacteria at the end of the growth period} &= 1 \times 2^{16} \\ &= 1 \times 65536 = 65536 \text{ bacteria} \end{aligned}$$

## Preventing bacterial growth

There are a number of ways to prevent the growth of bacteria. One way is to raise or lower the temperature. Also, chemicals can be used to stop them growing or to kill them. Disinfectants are chemicals used to kill bacteria in the environment around us. An antiseptic is a disinfectant that is safe to use on human skin. Antibiotics are chemicals that can be used

inside our bodies, which kill bacteria or prevent them from growing. You can investigate the effectiveness of temperature changes or chemicals at preventing the growth of bacteria. In each case you need a way of working out how many bacteria have grown.

### Investigating the effect of disinfectants and antibiotics



- You can add circles of filter paper soaked in different types or concentrations of disinfectant or antibiotic when you set up your culture plate. An area of clear agar gel indicates that the bacteria have been killed or cannot grow. This zone of inhibition can be measured and used to investigate the effect of different antiseptics or antibiotics on the growth of the bacteria.

### Calculating the effect of disinfectants and antibiotics on bacterial growth

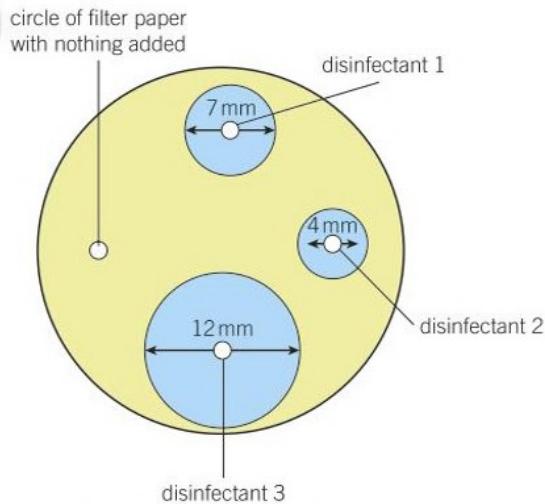


Measure the diameter of any circles of agar gel around your filter paper circles (Figure 3). Divide the diameter by 2 to find out the radius of the circle. Now you can work out the area of the clear circles of clear agar gel using  $\pi r^2$  and compare the effectiveness of the different chemicals (Figure 3 and Table 1).

**Table 1** Measuring the impact of different chemicals on bacterial growth

Chemical treatment	Measured diameter of clear circle in mm to 1 dp	Calculated radius of cleared circle ( $D/2 = r$ ) in mm to 1 dp	Calculated surface area of clear circle ( $\pi r^2$ ) in $\text{mm}^2$ to 1 dp
none	0.0	0.0	0.0
disinfectant 1	7.0	3.5	38.5
disinfectant 2	4.0	2.0	12.6
disinfectant 3	12.0	6.0	113.1

- Describe the difference between a disinfectant, an antiseptic, and an antibiotic. [3 marks]
  - A survey shows that disinfectants are most widely used in kitchens and toilets. Suggest why this is. [2 marks]
- If you set up a sealed culture of bacteria, they grow very fast to begin with but the rate of growth eventually slows down and stops. Suggest an explanation for this observation. [6 marks]
- A student set up a culture plate of bacteria and placed three filter paper circles containing different concentrations of antibiotic onto the surface. They were labelled A, B, and C. After five days, the diameters of the clear areas that developed were 5.0 mm, 10.2 mm, and 15.8 mm.
  - Calculate the surface area of agar cleared by the three discs. [3 marks]
  - Calculate how much more effective the highest concentration of antibiotic was compared to the lowest concentration. [2 marks]



**Figure 3** Investigating the effect of disinfectants on bacteria growth. The untreated filter paper acts as a control

### Key points

- Bacteria multiply by simple cell division as often as every 20 minutes if they have enough nutrients and a suitable temperature.
- You can investigate the effects of disinfectants and antibiotics on bacterial growth using agar plates and calculating the cross-sectional area of colonies grown or of clear areas of agar.

# B5.5 Preventing infections

## Learning objectives

After this topic, you should know:

- how the spread of disease can be reduced or prevented.



**Figure 1** In hospitals today, simply reminding doctors, nurses, and visitors to wash their hands more often is still an important way to prevent the spread of disease

People have recognised the symptoms of disease for many centuries. There are records of illnesses people recognise today from the ancient Egyptians and ancient Greeks. However, it is only in the past 150–200 years that people have really understood the causes of these diseases and how they are spread. The work of pioneering doctors and scientists such as Ignaz Semmelweis, Louis Pasteur, and Joseph Lister has helped develop the modern understanding of pathogens. Their work enabled people to prevent the spread of pathogens, and in some cases cure the diseases they cause.

### The work of Ignaz Semmelweis

Semmelweis was a doctor in the mid-1850s. At the time, many women in hospital died from childbed fever a few days after giving birth. However, no one knew what caused it.

Semmelweis noticed that his medical students went straight from dissecting a dead body to delivering a baby without washing their hands. The women delivered by medical students and doctors rather than midwives were much more likely to die. Semmelweis wondered if they were carrying the cause of disease from the corpses to their patients.

He noticed that another doctor died from symptoms identical to childbed fever after cutting himself while working on a body. This convinced Semmelweis that the fever was caused by some kind of infectious agent. He therefore insisted that his medical students wash their hands before delivering babies. Immediately, fewer mothers died from the fever. However, other doctors were very resistant to Semmelweis's ideas.

### Other discoveries

Also in the mid- to late-19th century:

- Louis Pasteur showed that microorganisms caused disease. He developed **vaccines** against diseases such as anthrax and rabies.
- Joseph Lister started to use antiseptic chemicals to destroy pathogens before they caused infection in operating theatres.
- As microscopes improved, it became possible to see pathogens more clearly. This helped convince people that they were really there.

Understanding how communicable diseases are spread from one person to another helps us prevent it happening.

### Preventing the spread of communicable diseases

There are a number of key ways to help prevent the spread of communicable diseases between people, between animals and people, and between plants.

## Hygiene

Simple hygiene measures are one of the most effective ways of preventing the spread of pathogens. These include:

- Hand washing, especially after using the toilet, before cooking, or after contact with an animal or someone who has an infectious illness.
- Using disinfectants on kitchen work surfaces, toilets, etc. to reduce the number of pathogens.
- Keeping raw meat away from food that is eaten uncooked to prevent the spread of pathogens.
- Coughing or sneezing into a handkerchief, tissue, or your hands (and then washing your hands).
- Maintaining the hygiene of people and agricultural machinery to help prevent the spread of plant diseases.

## Isolating infected individuals

If someone has an infectious disease, especially a serious disease such as Ebola or cholera, they need to be kept in isolation. The fewer healthy people who come into contact with the infected person, the less likely it is that the pathogens will be passed on. This is also true of plants infected with diseases but it is only possible with smaller plants that can be moved and destroyed easily.

## Destroying or controlling vectors

Some communicable diseases are passed on by vectors. For example, mosquitoes carry a range of diseases, such as malaria and dengue fever. Houseflies can carry over 100 human diseases, while rats also act as vectors of disease. Aphids transmit over 150 different plant diseases and different types of beetle carry disease to plants in the form of viral, bacterial, and fungal pathogens. If the vectors are destroyed, the spread of the disease can be prevented. By controlling the number of vectors, the spread of disease can be greatly reduced.

## Vaccination

During vaccination, doctors introduce a small amount of a harmless form of a specific pathogen into your body. As a result, if you come into contact with the live pathogen, you will not become ill as your immune system will be prepared. Vaccination is a very successful way of protecting large numbers of humans and animals against serious diseases. However, it cannot protect plants against disease as they do not have an immune system.



**Figure 2** Isolation of infected patients played a major role in the control of the deadly disease Ebola in West Africa during the 2014 outbreak

## Synoptic link

You will learn more about preventing communicable diseases in Topic B6.1.

- 1 Give three examples of things people can do to reduce the spread of pathogens to lower the risk of disease. [3 marks]
- 2 For each example you have chosen in your answer to Question 1, explain how it helps to prevent the spread of disease. [6 marks]
- 3 Suggest why other doctors were so resistant to Semmelweis's ideas. [6 marks]

## Key points

- The spread of disease can be prevented by simple hygiene measures, by destroying vectors, by isolation of infected individuals, and by vaccination.

# B5.6 Viral diseases

## Learning objectives

After this topic, you should know:

- some examples of plant and animal diseases caused by viruses including measles, HIV/AIDS, and tobacco mosaic virus.



**Figure 1** A measles rash is now a rare sight in the UK

Viruses can infect and damage all types of cells. The diseases they cause can be mild or potentially deadly. Scientists have not developed medicines to cure viral diseases, so it is important to stop them spreading. In people, viral diseases often start relatively suddenly. The symptoms are the result of the way the body reacts to the viruses damaging and destroying cells as they reproduce. See below for examples of viral diseases.

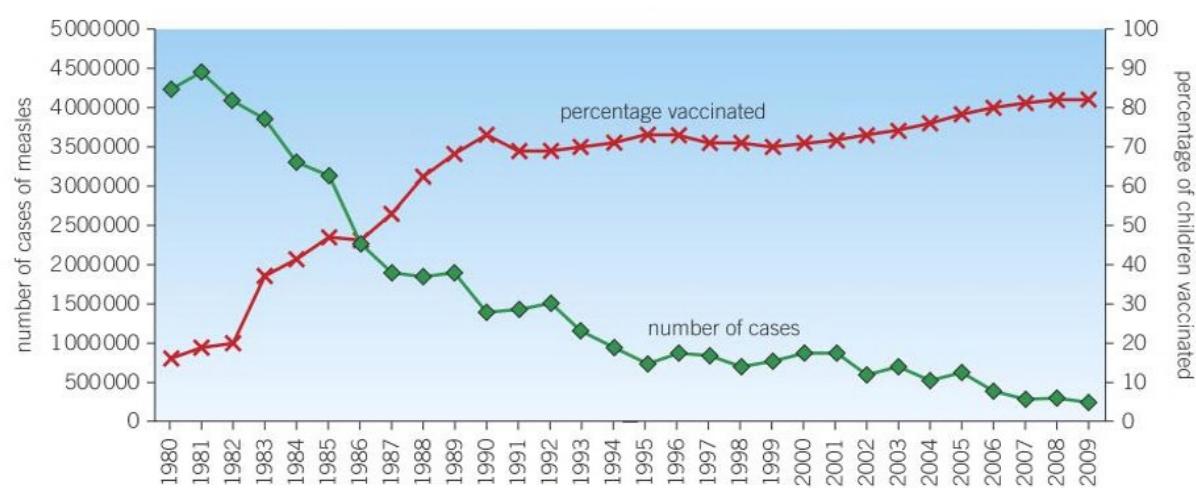
### Measles

The main symptoms of measles are a fever and a red skin rash. The virus is spread by the inhalation of droplets from coughs and sneezes and is very infectious. Measles is a serious disease that can cause blindness and brain damage and may be fatal if complications arise. In 2013, 145 700 people globally died of measles. There is no treatment for measles, so if someone becomes infected they need to be isolated to stop the spread of the virus. Measles is now rare in the UK as a result of improved living conditions and a vaccination programme for young children. The challenge now is to vaccinate children globally and make deaths from measles a thing of the past (Figure 2).

### HIV/AIDS

Around 35 million people globally are infected with HIV, a virus that can eventually lead to AIDS. In 2013, around 1.5 million people died of HIV-related illnesses. Many people do not realise they are infected with HIV, because the virus only causes a mild, flu-like illness to begin with. HIV attacks the immune cells and after the initial mild illness it remains hidden inside the immune system, sometimes for years, until the immune system is so badly damaged that it can no longer deal with infections or certain cancers. At this point the patient has developed AIDS.

The time between infection with HIV and the onset of the final stages of AIDS is affected by many factors. These include the level of nutrition and overall health of the person, as well as access to antiretroviral drugs.



**Figure 2** World Health Organisation data on the trends in global vaccination against measles and the numbers of reported measles cases

HIV is spread by direct sexual contact and the exchange of body fluids such as blood, which occurs when drug users share needles or when unscreened blood is used for transfusions. HIV can also be passed from mother to child in breast milk.

There is no cure for HIV/AIDS and no vaccine against it. The spread of the disease can be prevented by using condoms, not sharing needles, screening blood used for transfusions, and HIV-positive mothers bottle-feeding their children.

The regular use of antiretroviral drugs can prevent the development of AIDS for many years and give HIV positive people an almost normal life expectancy. Unfortunately, the majority of people infected with HIV live in areas such as sub-Saharan Africa where it is hard to get antiretroviral drugs. In these areas the life expectancy for people with HIV/AIDs is still very low. To have the best chance of long-term survival, antiretroviral drugs must be started as soon as possible after infection.

## Tobacco mosaic virus

Tobacco mosaic virus (TMV) was the first virus ever to be isolated. It is a widespread plant pathogen that affects around 150 species of plants including tomatoes and tobacco plants. It causes a distinctive 'mosaic' pattern of discoloration on the leaves as the virus destroys the cells. This affects the growth of the plant because the affected areas of the leaf do not photosynthesise. TMV can seriously reduce the yield of a crop.

It is spread by contact between diseased plant material and healthy plants, and insects can act as vectors. The virus can remain infectious in the soil for about 50 years. There is no treatment and farmers now grow TMV-resistant strains of many crop plants. Good field hygiene and good pest control can help prevent the spread of TMV.



**Figure 3** Tobacco mosaic virus causes a typical pattern of damage in many different types of plants

## Key points

- Measles virus is spread by droplet infection. It causes fever and a rash and can be fatal. There is no cure. Isolation of patients and vaccination prevents spread.
- HIV initially causes flu-like illness. Unless it is successfully controlled with antiretroviral drugs the virus attacks the body's immune cells. Late stage HIV infection, or AIDS, occurs when the body's immune system becomes so badly damaged it can no longer deal with other infections or cancers. HIV is spread by sexual contact or by the exchange of body fluids, such as blood, which occurs when drug users share needles.
- Tobacco mosaic virus is spread by contact and vectors. It damages leaves and reduces photosynthesis. There is no treatment. Spread is prevented by field hygiene and pest control.

- |  |  |
|--|--|
| <b>1</b> <b>a</b> Describe the main symptoms of measles. [2 marks]<br><b>b</b> Suggest why measles is now rare in the UK. [2 marks]  |  |
| <b>2</b> <b>a</b> Describe the link between HIV and AIDS. [1 mark]<br><b>b</b> Explain why untreated HIV is usually fatal. [4 marks]   |  |
| <b>3</b> Using Figure 2, calculate the following.  |  |
| <b>a</b> The number of cases of measles globally between:  |  |
| <b>i</b> 1980 and 1985 [3 marks]   |  |
| <b>ii</b> 2000 and 2005. [3 marks]   |  |
| <b>b</b> Assuming that 5% of patients (cases) will die, calculate how many people died of measles in each time period. [4 marks]   |  |
| <b>c</b> Explain the apparent link between vaccination rates and cases of measles globally.  [4 marks]                      |  |
| <b>4</b> Evaluate the similarities and differences between tobacco mosaic virus in plants and measles in people.  [6 marks] |  |

# B5.7 Bacterial diseases

## Learning objectives

After this topic, you should know:

- some examples of plant and animal diseases caused by bacteria, including *Salmonella* food poisoning and gonorrhoea.

## Synoptic link



You can learn more about orders of magnitude in Maths skills MS2.

You will learn more about antibiotics in Topic B6.2, and more about antibiotic resistance in Topic B15.8.



**Figure 1** Handling raw poultry, undercooked food, or salads contaminated with raw meat through poor kitchen hygiene are all common sources of the *Salmonella* bacteria that can cause food poisoning.

Bacterial diseases affect animals and plants. In the early 20th century, more than 30% of all deaths in the USA were due to infectious diseases. That is now an order of magnitude lower, and most of the infectious diseases that cause death are viral. Improved living standards and vaccinations have had a major effect on the incidence and death rate of communicable diseases in countries such as the USA and UK.

The development of antibiotics is the other key factor in combating bacterial diseases. Antibiotics kill bacteria or stop them growing and cure bacterial diseases. Unfortunately, bacteria are becoming resistant to many antibiotics and more people are dying from bacterial diseases again.

### Salmonella food poisoning

*Salmonella* are bacteria that live in the guts of many different animals. They can be found in raw meat, poultry, eggs, and egg products such as mayonnaise. If these bacteria get into our bodies, they disrupt the balance of the natural gut bacteria and can cause *Salmonella* food poisoning. One common cause of infection is eating undercooked food, when the bacteria have not been killed by heating. Another is, eating food prepared in unhygienic conditions where food is contaminated with *Salmonella* bacteria from raw meat.

The symptoms develop within 8–72 hours of eating infected food. Fever, abdominal cramps, vomiting, and diarrhoea are caused by the bacteria and the toxins they secrete. For many people *Salmonella* infections are unpleasant but don't last many days and no antibiotics are given. In very young children and the elderly it can be fatal, usually because of dehydration. In countries where there is malnutrition, *Salmonella* is more serious. The World Health Organisation estimates that globally around 2.2 million people, mainly children under 5 years old, are killed by sickness and diarrhoea each year, including *Salmonella* food poisoning.

In the UK, poultry are vaccinated against *Salmonella* to control the spread of the disease. *Campylobacter*, another bacterium found in chickens, still causes around 280 000 cases of food poisoning each year. To prevent food poisoning, keep raw chicken away from food that is eaten uncooked, avoid washing raw chicken (it sprays bacteria around the kitchen), wash hands and surfaces well after handling raw chicken, and cook chicken thoroughly.

### Gonorrhoea

Gonorrhoea is a **sexually transmitted disease (STD)**, which are also known as sexually transmitted infections (STIs). It is spread by unprotected sexual contact with an infected person. Like many STDs, gonorrhoea has symptoms in the early stages but then becomes relatively symptomless. The early symptoms include a thick yellow

or green discharge from the vagina or penis and pain on urination. However, about 10% of infected men and 50% of infected women get no symptoms at all. Untreated gonorrhoea can cause long-term pelvic pain, infertility, and ectopic pregnancies. Babies born to infected mothers may have severe eye infections and even become blind.

Gonorrhoea is bacterial, so it can be treated with antibiotics. Originally it was easily cured using penicillin but now many antibiotic-resistant strains of gonorrhoea have evolved so it is increasingly difficult to treat. All sexual partners of an infected individual must be treated with antibiotics to prevent the disease spreading in the community. The spread of gonorrhoea can also be prevented by using a barrier method of contraception such as a condom and by reducing the number of sexual partners.

## Bacterial disease in plants

There are relatively few bacterial diseases of plants and these diseases are usually found in tropical and sub-tropical regions. *Agrobacterium tumefaciens* is a bacterium that causes crown galls – a mass of unspecialised cells that often grow at the join between the root and the shoot in infected plants (Figure 2). It infects many different plant types including fruit trees, vegetables, and garden flowering plants. The bacteria insert plasmids into the plant cells and cause a mass of new undifferentiated genetically modified cells to grow. For this reason, these bacteria have become a key tool for scientists when genetically modifying plant cells. Scientists make use of the way the bacteria naturally infect plant cells and give them new added genes. They manipulate the bacteria so they carry desirable genes into the cells they infect.



**Figure 2** The bacteria that cause galls like this one on a chrysanthemum plant are also widely used in genetically modifying plants

### Synoptic link

You will find out more about the use of bacteria in the production of genetically modified plants in B14.4 and B14.5.



### Key points

- *Salmonella* is spread through undercooked food and poor hygiene. Symptoms include fever, abdominal cramps, diarrhoea, and vomiting caused by the toxins produced by the bacteria. In the UK, poultry are vaccinated against *Salmonella* to control the spread of disease.
- Gonorrhoea is a sexually transmitted disease. Symptoms include discharge from the penis and vagina and pain on urination. Treatment involves using antibiotics, although many strains are now resistant. Using condoms and limiting sexual partners prevents spread.
- There are relatively few bacterial diseases of plants but *Agrobacterium tumefaciens* causes galls.

- 1 Name one way that antibiotics work to cure bacterial infections. [1 mark]
- 2 a Describe how people become infected with food poisoning caused by *Salmonella*. [2 marks]
  - b Doctors in the UK rarely treat *Salmonella* food poisoning with antibiotics. Suggest reasons for this. [3 marks]
- 3 a Gonorrhoea is an STD. Explain what this means. [2 marks]
  - b Until recently gonorrhoea was relatively easy to treat. Explain this statement. [2 marks]
  - c Suggest three ways of preventing the spread of gonorrhoea. [3 marks]
  - d Describe the implications of increased antibiotic resistance in the bacteria causing gonorrhoea for the 106 million people who are infected with the disease each year. [4 marks]
- 4 Write a paragraph for your local newspaper on food preparation for summer barbeques to help people avoid *Salmonella* and other forms of food poisoning. [6 marks]

# B5.8 Diseases caused by fungi and protists

## Learning objectives

After this topic, you should know:

- some examples of plant diseases caused by fungi, including rose black spot
- some examples of animal diseases caused by protists, including malaria
- how the spread of diseases can be reduced or prevented.



**Figure 1** Roses are beautiful flowers but fungal blackspot infections weaken the plants and reduce the flowers. Similar fungal diseases weaken and destroy crop plants around the world

Fungi and protists are less well known than bacteria and viruses but they are also important pathogens. Some of the diseases they cause are of great significance, both in terms of global economies and of human suffering.

## Fungal diseases

There are relatively few fungal diseases that affect people. Athlete's foot is a well-known, relatively minor fungal skin condition. A small number of human fungal diseases can be fatal when they attack the lungs or brains of people who are already ill. Damaged heart valves can also develop serious fungal infections. However, these conditions are rare. Antifungal drugs are usually effective against skin fungi like athlete's foot, but it can be hard to treat deep-seated tissue infections.

In plants, however, fungal diseases are common and can be devastating. Huge areas of crops, from cereals to bananas are lost every year as a result of fungal infections, including stem rusts and various rotting diseases.

## Rose black spot

Rose black spot is a fungal disease of rose leaves. It causes purple or black spots to develop on the leaves and it is a nuisance in gardens and for commercial flower growers. The leaves often turn yellow and drop early. This weakens the plant because it reduces the area of leaves available for photosynthesis. As a result the plant does not flower well – and the main reason people grow roses is for the lovely flowers.

The spores of the fungus are spread in the environment, carried by the wind. They are then spread over the plant after it rains in drips of water that splash from one leaf or plant to another. The spores stay dormant over winter on dead leaves and on the stems of rose plants. Gardeners try to prevent the spread by removing and burning affected leaves and stems. Chemical fungicides can also help to treat the disease and prevent it spreading. Horticulturists have bred types of roses that are relatively resistant to black spot but the disease still cannot be prevented or cured.

## Diseases caused by protists

Protists (a type of single-celled organism) cause a range of diseases in animals and plants. They are relatively rare pathogens but the diseases they cause are often serious and damaging to those infected. Diseases caused by protists usually involve a vector that transfers the protist to the host. One of the best known and globally serious protist diseases is malaria.

## Malaria

Malaria is a disease caused by protist pathogens that are parasites – they live and feed on other living organisms. The life cycle of the protists includes time in the human body and time in the body of a female *Anopheles*

mosquito. The protists reproduce sexually in the mosquito and asexually in the human body. The mosquitoes act as vectors of the disease. The female mosquito needs two meals of human blood before she can lay her eggs, and this is when the protists are passed into the human bloodstream. The protists travel around the human body in the circulatory system. They affect the liver and damage red blood cells. Malaria causes recurrent episodes of fever and shaking when the protists burst out of the blood cells, and it can be fatal. It weakens the affected person over time even if it does not kill them. Globally several hundred million cases of malaria occur each year, and around 660 000 people die from the disease.



**Figure 2** The malaria protist causes disease and mosquitoes act as very effective vectors

If malaria is diagnosed quickly, it can be treated using a combination of drugs, but this is not always available in the countries most affected by malaria. The protists have also become resistant to some of the most commonly used medicines. The spread of malaria can be controlled in a number of ways, most of which target the mosquito vector. These include:

- Using insecticide-impregnated insect nets to prevent mosquitoes biting humans and passing on the protists (Figure 3).
- Using insecticides to kill mosquitoes in homes and offices.
- Preventing the vectors from breeding by removing standing water and spraying water with insecticides to kill the larvae.
- Travellers can take antimalarial drugs that kill the parasites in the blood if they are bitten by an infected mosquito.

- 1 a** Describe three ways in which fungal diseases such as black spot or stem rust can be spread from plant to plant. [3 marks]
- b** Explain why roses affected by black spot produce fewer, smaller flowers than healthy plants. [3 marks]
- 2 a** Describe how malaria is passed from one person to another. [2 marks]
- b** Insecticide-treated mosquito nets help prevent the spread of malaria in two ways. Explain how. [2 marks]
- 3** For travellers from the UK going to an area with malaria, doctors suggest the ABCD approach. This stands for Awareness, Bite prevention, Chemoprophylaxis (antimalarial medicines), and Diagnosis. Explain how each of these points would reduce the chance of becoming seriously ill with malaria. [6 marks]

## Synoptic links

You will learn more about asexual and sexual reproduction in Topics B13.1, B13.2, and B13.3.



**Figure 3** Simple control measures such as insecticide-treated mosquito nets have reduced the incidence of malaria by as much as 75% in some countries

## Key points

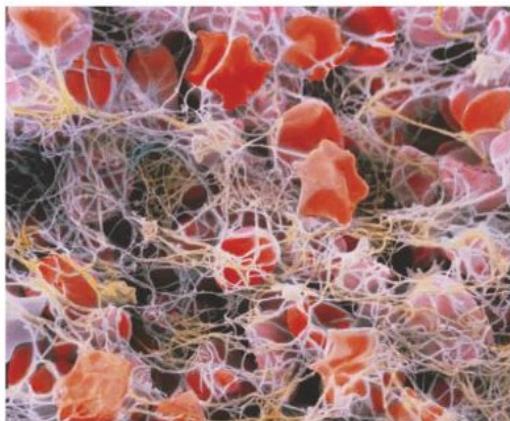
- Rose black spot is a fungal disease spread in the environment by wind and water. It damages leaves so they drop off, affecting growth as photosynthesis is reduced. Spread is controlled by removing affected leaves and chemical sprays, but is not very effective.
- Malaria is caused by parasitic protists and is spread by the bite of female mosquitoes. It damages blood and liver cells, causes fevers and shaking, and can be fatal. Some drugs are effective if given early but protists are becoming resistant. Spread is reduced by preventing the vectors from breeding and by using mosquito nets to prevent people from being bitten.

# B5.9 Human defence responses

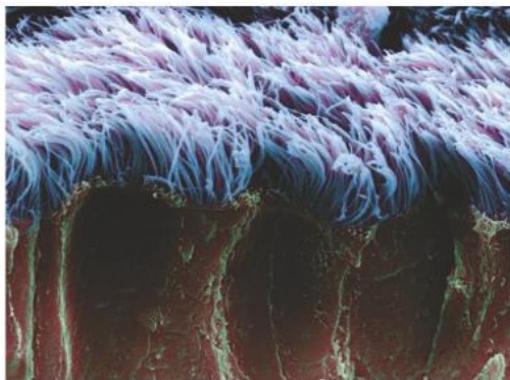
## Learning objectives

After this topic, you should know:

- how your body stops pathogens getting in
- how your white blood cells protect you from disease.



**Figure 1** The scabs that restore the protective barrier of the skin and prevent pathogens getting in are made of red blood cells tangled in protein strands formed by platelets – magnification  $\times 1830$



**Figure 2** The cilia of the airways beat together to move mucus containing trapped pathogens away from the lungs

The mucus produced from your nose turns green when you have a cold. Why does this happen? It is all part of the way your body defends itself against disease.

## Preventing microorganisms getting into your body

Each day, you meet millions of disease-causing microorganisms. Every body opening as well as any breaks in the skin give pathogens a way in. The more pathogens that get into your body, the more likely it is that you will get an infectious disease. Fortunately, your body has many defence mechanisms that work together to keep the pathogens out.

### Skin defences

- Your skin covers your body and acts as a barrier. It prevents bacteria and viruses reaching the tissues beneath. If you damage or cut your skin, the barrier is broken but your body restores it. You bleed, and the platelets in your blood set up a chain of events to form a clot that dries into a scab (Figure 1). This forms a seal over the cut, stopping pathogens getting in. It also stops you bleeding to death.
- Your skin produces antimicrobial secretions to destroy pathogenic bacteria.
- Healthy skin is covered with microorganisms that help keep you healthy and act as an extra barrier to the entry of pathogens.

## Defences of the respiratory and digestive systems

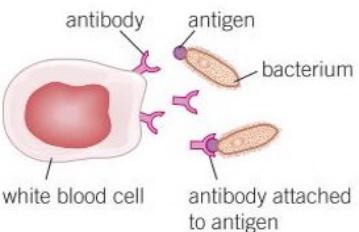
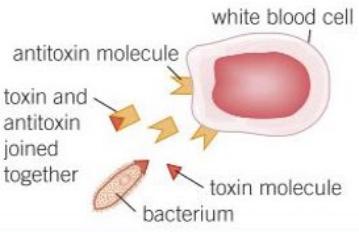
Your respiratory system is a weak link in your body defences. Every time you breathe in, you draw air full of pathogens into the airways of the lungs. In the same way, you take food and drink, as well as air, into your digestive system through your mouth. Both systems have good defences to help prevent pathogens constantly causing infections.

- Your nose is full of hairs and produces a sticky liquid, called mucus. The hairs and mucus trap particles in the air that may contain pathogens or irritate your lungs. If you spend time in an environment with lots of air pollution, the mucus you produce when you blow your nose is blackened, showing that the system works.
- The trachea and bronchi also secrete mucus that traps pathogens from the air. The lining of the tubes is covered in cilia – tiny hair-like projections from the cells. The cilia beat to waft the mucus up to the back of the throat where it is swallowed.
- The stomach produces acid and this destroys the microorganisms in the mucus you swallow, as well as the majority of the pathogens you take in through your mouth in your food and drink.

## The immune system – internal defences

In spite of your body's defence mechanisms, some pathogens still get inside your body. Once there, they will meet your second line of defence – the white blood cells of your immune system. The immune system will try to destroy any pathogens that enter the body in several ways.

**Table 1** Ways in which your white blood cells destroy pathogens and protect you against disease

Role of white blood cell	How it protects you against disease
<b>Ingesting microorganisms</b> 	Some white blood cells ingest (take in) pathogens, digesting and destroying them so they cannot make you ill.
<b>Producing antibodies</b> 	Some white blood cells produce special chemicals called antibodies. These target particular bacteria or viruses and destroy them. You need a unique antibody for each type of pathogen. When your white blood cells have produced antibodies once against a particular pathogen, they can be made very quickly if that pathogen gets into the body again. This stops you getting the disease twice.
<b>Producing antitoxins</b> 	Some white blood cells produce antitoxins. These counteract (cancel out) the toxins released by pathogens.

The different body systems work together to help protect you from disease. For example, some white blood cells contain green-coloured enzymes. These white blood cells destroy the cold viruses and any bacteria trapped in the mucus of your nose when you have a cold. The dead white blood cells, along with the dead bacteria and viruses, are removed in the mucus, making it look green.

- 1 Describe how each action can prevent the spread of disease.
  - a Washing your hands before preparing a salad. [1 mark]
  - b Throwing away tissues after you have blown your nose. [1 mark]
  - c Making sure that sewage does not get into drinking water. [1 mark]
- 2 Explain why the following symptoms of certain diseases increase your risk of getting infections.
  - a Your blood won't clot properly. [2 marks]
  - b The number of white cells in your blood falls. [3 marks]
- 3 Explain how your white blood cells help to prevent you from suffering from communicable diseases.  [6 marks]

## Go further

Very rarely a baby is born without an immune system. This leaves the infant vulnerable to infections and is fatal if it is not treated. In autoimmune diseases, your immune system starts to destroy your own tissues. This can lead to many problems, from hives to arthritis.

## Synoptic links

Remind yourself about the production of acid in the stomach by looking at Topic B3.7, about your blood and clotting in Topic B4.1, and about the structure of the breathing system in Topic B4.5.

## Key points

- Your body has several lines of defence against the entry of pathogens. These include the skin (barrier and antimicrobial), the nose, the trachea, the bronchi, and the stomach.
- Your white blood cells help to defend you against pathogens by ingesting them and by making antibodies and antitoxins.



# B5.10 More about plant diseases

## Learning objectives

After this topic, you should know:

- the variety of plant pathogens
- how mineral deficiencies can cause non-communicable diseases in plants
- **H** how to detect plant diseases.

## Synoptic link

You can remind yourself of the importance of the phloem in Topic B4.7.

The global loss of food crops to plant pathogens is 15–40% a year. Understanding the causes and preventing the spread of plant diseases can help provide a secure food supply for everyone.

## More plant pathogens

As you have seen, plants are vulnerable to viruses, bacteria, and fungi but they are also attacked by pests that cause a lot of damage. Insect pests may both destroy plants directly and act as vectors of disease. One important group of insect plant pests is the **aphids**. Aphids have sharp mouthparts that penetrate into the phloem vessels of the plant so they can feed on the sugar-rich phloem sap. Aphids attack in huge numbers, depriving the plant cells of the products of photosynthesis. This can seriously damage and weaken the plant. Aphids also act as vectors, transferring viruses, bacteria, and fungi from diseased plants into the tissues of healthy plants on their mouthparts.

Aphids can be destroyed using chemical pesticides or, in enclosed spaces such as greenhouses, using biological pest control. Releasing aphid-eating insects such as ladybirds and their larvae can control the pathogen population so it does not have an impact on the success of the crop.

Other plant pests, including tiny nematode worms and many insect larvae that live in the soil, feed in or on plant roots, damaging them so they cannot absorb water and mineral ions effectively. As a result the plant fails to grow and thrive.



**Figure 1** Aphids can destroy plants, but ladybirds destroy aphids



**Figure 2** Chlorosis in a leaf due to magnesium ion deficiency in the soil

## Mineral deficiency – non-communicable diseases in plants

Some plant diseases are the result of mineral deficiencies in the soil where the plants are growing. They are non-communicable – they are not passed from one plant to another. For example, plants need a good supply of nitrate ions from the soil to convert the sugars made in photosynthesis into proteins needed for growth in protein synthesis. If there is a nitrate deficiency in the soil, protein growth will be limited, the growth of plants will be stunted, and they will not produce a crop properly.

Plants take magnesium ions from the soil to make the chlorophyll needed for photosynthesis. If the level of magnesium ions in the soil is low, the plant cannot make enough chlorophyll. The leaves become yellow and growth slows down because the plant cannot photosynthesise fully. The yellowing of the leaves due to lack of magnesium ions is known as **chlorosis**.

If the missing mineral ions are replaced using fertilisers fairly quickly, the damage can be repaired and the plant recovers. If not it will eventually die.

## Detecting disease

In plants as in people, the sooner a disease can be detected, the more likely it is that it can be treated effectively. Fast detection also helps reduce the spread of disease between plants, because diseased plants can be treated or removed. Symptoms of disease in plants include:

- stunted growth (e.g., nitrate deficiency)
- spots on leaves (e.g., black spot fungus on roses)
- areas of decay or rotting (e.g., black spot on roses, blights on potatoes)
- growths (e.g., crown gall caused by bacterial infections)
- malformed stems and leaves (e.g., due to aphid or nematode infestation)
- discolouration (e.g., yellowing or chlorosis in magnesium deficiency, mosaic patterns resulting from tobacco mosaic virus)
- presence of visible pests (e.g., aphids, caterpillars).

Identifying plant diseases is not easy. Many diseases give similar symptoms. However, it is very important to identify the cause of problems in plants. Some can be treated using pesticides or antifungal treatments. Mineral deficiencies can also be treated. But the sooner treatment starts, the more likely it is to be successful. Some diseases cannot be treated – in such cases, it is important to remove the diseased plants as quickly as possible to prevent the pathogens spreading through the garden, field, or woodland.

Diseases in garden plants may be identified by comparing the symptoms in the living plant with disease descriptions in a gardening manual or online.

When the symptoms of disease occur in crop plants or forest trees, experts may visit the field or woodland to observe the symptoms in their natural environment. They may then take samples of diseased materials to the laboratory to identify the pathogen using techniques that include DNA analysis.

Plant scientists, foresters, farmers, and market gardeners can use testing kits that contain monoclonal antibodies to identify the presence of certain plant pathogens, for example, the fungal pathogen *Botrytis*.

- 1 Describe the effect of the following on the growth of a plant:
  - a lack of nitrate ions in the soil. [2 marks]
  - b lack of magnesium ions in the soil. [2 marks]
- 2 Some plants growing in soil with a good supply of minerals show the symptoms of mineral deficiencies such as stunted growth and yellowed leaves. Suggest a reason for this. [4 marks]
- 3 **H** Construct a diagnostic table for common plant diseases showing common symptoms, possible pathogens or pests, and examples of specific diseases to include in either a gardening, farming, or forestry website, stating your chosen audience. [4 marks]

## Go further

Plants and plant pathogens are locked in a deadly battle. Plants have developed many defences against their common pathogens. These include signalling systems that allow damaged cells to warn other cells within the plant that they are under attack. Some plants can even signal to other plants around them, allowing them to get their defences in place before an attack starts.

## Synoptic links

- H** You will learn more about DNA analysis in Topic B15.10 and about monoclonal antibodies in Topic B6.5 and Topic B6.6.



## Key points

- Plants can be infected by a range of viral, bacterial, and fungal pathogens as well as insect pests.
- Plants can be damaged by a range of ion deficiency conditions.
- **H** Plant diseases can be detected by a range of symptoms and identified in a number of ways, including gardening manuals and laboratory tests, some involving monoclonal antibodies.



# B5.11 Plant defence responses

## Learning objectives

After this topic, you should know:

- that plants have evolved a variety of mechanisms to defend themselves against pathogens and herbivores.



mint



witch hazel



Hypericum

**Figure 1** Mint and witch hazel produce mildly antimicrobial chemicals, while chemicals from some types of *Hypericum* may even be effective against antibiotic-resistant strains of bacteria

You are familiar with some of the ways the human body defends itself against the entry of pathogens. Plants have also evolved some very effective defences against the attacks of microorganisms, insects, and even larger herbivores. Plants have evolved both physical and chemical defences against pathogenic microorganisms:

## Physical barriers

Plants have a number of physical barriers that reduce the invasion of pathogens:

- The cellulose cell walls that strengthen plant cells also help to resist invasion by microorganisms. This is one reason why the actions of aphids that pierce the cellulose cell walls are so damaging. It breaches the barrier and gives pathogens a way into the cells.
- The tough waxy cuticle on the surface of leaves acts as a barrier to the entry of pathogens. It is only at the stomata that pathogens actually have access to the cells within the leaf.
- Bark on trees, and a layer of dead cells on the outside of stems, form a protective layer that is hard for pathogens to penetrate. When the dead cells are lost or shed, the pathogens fall off with them.
- Leaf fall – deciduous trees lose their leaves in autumn. Any pathogens that infect the leaves, such as rose black spot, fall off the tree when the leaves are lost.

## Chemical barriers

Many plants produce antibacterial chemicals that protect them against invading pathogens, and these are very effective at preventing bacterial diseases in many plants. Until recently people have not extracted and used plant chemicals as antibiotics. As current antibiotics become less effective, scientists are increasingly investigating plant antibacterial chemicals to see if they can be adapted for use as antibiotics against human pathogens. Mint and witch hazel are often used as mild antiseptics in cosmetics and over-the-counter medicines. Compounds from plants including pines, cypress, and euphorbias also have promising antibiotic properties.

## Defence against herbivores

Plants don't just defend themselves against microorganisms. They also defend themselves against the large and small animals that want to eat them. Obviously if a plant is eaten by a large herbivore it is destroyed and will not flower and reproduce. If smaller herbivores such as aphids, caterpillars, or beetles attack a plant, they can damage the plants and act as vectors of pathogens themselves. Not only that, the damage they do may allow other disease-causing organisms to get in. Some of these defences are chemical and others are mechanical (Figure 2).

		
Poisons to deter herbivores, for example, foxgloves, deadly nightshade and yew. Animals quickly learn to avoid eating plants that make them feel unwell.	Thorns to make it unpleasant or painful for large herbivores to eat them, for example, brambles, cacti and gorse. Thorns are unlikely to deter insects.	Hairy stems and/or leaves deter insects and larger animals from feeding on them or laying their eggs on the leaves or stems, for example, lamb's ears, and some pelargoniums. Some plants combine hairs with poisons, for example, nettles.
		
Drooping or curling when touched – a rare but effective adaptation is for the leaves to collapse suddenly, dislodging insects and frightening larger animals, for example, the sensitive plant <i>Mimosa pudica</i> .	Mimicry – some plants droop to mimic unhealthy plants and this tricks animals into not eating them. Some mimic butterfly eggs on their surfaces, so real butterflies do not lay eggs on them to avoid competition with other caterpillars.	

**Figure 2** Plant defence mechanisms: poisons act as a chemical defence while, thorns, hairy stems/leaves, drooping/curling, and mimicry are all mechanical adaptations for defence.

- 1 **a** Name three ways a plant might defend itself against pathogens. [3 marks]
- b** Name three ways a plant might defend itself against attack by a herbivore. [3 marks]
- 2 Explain the way each of the plant defences you have listed in your answer to Question 1 works. [6 marks]
- 3 Describe the similarities and differences between the ways plants and people defend themselves against the attack of pathogens.  [6 marks]

### Key points

- Physical plant defences against invasion by microorganisms include cellulose cell walls, tough waxy cuticles, and layers of bark or dead cells (or dead leaves) which fall off.
- Chemical plant defences include antibacterial chemicals and poisons to deter herbivores.
- Many plants have mechanical adaptations against herbivores such as thorns and hairs, leaves that droop or curl when touched, and mimicry to trick animals.

# B5 Communicable diseases

## Summary questions

- 1 As a result of budget cuts, your school has decided to buy a cheaper disinfectant to use for washing the floors, and to tell cleaners to dilute the disinfectant more when they use it so that it lasts longer. The biology department decides to check if this risks the spread of more communicable diseases in the school. Describe how you would compare the effectiveness of the two disinfectants and the effect of reducing the concentration of disinfectant used to wash the school floors. Include any health and safety issues in your procedure. [6 marks]
- 2 On the surface of freshly picked strawberries we can find a type of bacteria that makes them rot. At room temperature the mean division time of these bacteria is 60 minutes. If the fruit are placed in the fridge, the mean division time is 6 hours.
- Explain the difference in the mean division time of the bacteria at room temperature and in the fridge. [3 marks]
  - Calculate how many bacteria would be produced over 24 hours from each bacterium on the surface of a strawberry kept:
    - at room temperature [3 marks]
    - in the fridge. [3 marks]
  - What is the percentage difference in the numbers of rot-causing bacteria between the fruit stored in the fridge and the fruit stored at room temperature? [2 marks]
- d Someone suggested heating the strawberries to 100 °C for a few minutes to prevent them going bad. Give the pros and cons of this idea. [4 marks]
- 3 Use the data in Figure 1 and your knowledge of HIV/AIDS to answer the following questions.

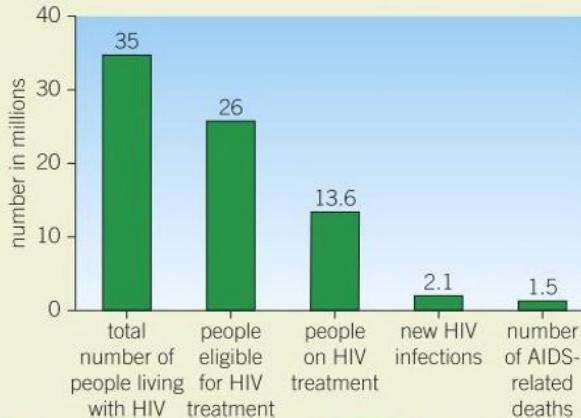


Figure 1 Data on the global HIV/AIDS epidemic in one year

- What is the difference between HIV and AIDS? [2 marks]
  - Approximately 70% of the people living with HIV/AIDS and 70% of the deaths from AIDS are in sub-Saharan Africa. Using data from Figure 1:
    - Calculate the approximate numbers of people living with HIV and dying of AIDS in sub-Saharan Africa in 2013. [4 marks]
    - Explain why your answer is only approximate. [3 marks]
  - i What percentage of the people suitable for treatment with antiretroviral therapy (ART) actually get treatment? [2 marks]
  - Suggest reasons for this. [3 marks]
  - i Give three ways of preventing the spread of HIV. [3 marks]
  - Explain how each method works. [6 marks]
- 4 Table 1 shows the percentage of crops lost to disease from a study published in 2006, both with and without crop protection measures:
- Display these results graphically or in a chart. [5 marks]
  - Which crop benefitted most from the protective measures? Explain your answer. [3 marks]
  - Which crop was least affected by crop protection measures? Explain your answer [3 marks]

Table 1

	% crop loss without protection	% crop loss with protection
wheat	49.8	28.2
rice	75.0	35.4
maize	68.8	31.2
potatoes	84.8	40.3
soybeans	60.1	26.3
cotton	82.0	28.8

Source: Oerke et al., *Journal of Agricultural Science* 2006

- i Name three different types of plant diseases [3 marks]
- Explain how the diseases might affect the yield of a crop. [6 marks]
- Suggest three ways in which farmers can help to protect their crops from plant diseases. [3 marks]
- f Explain, using your answer to part a, why research into the prevention of plant diseases is so important to human health and well being. [6 marks]

## Practice questions

**01** Pathogens cause infectious diseases.

**01.1** Match each disease to the type of pathogen that causes the disease.

Disease
AIDS
malaria
<i>salmonella</i> food poisoning

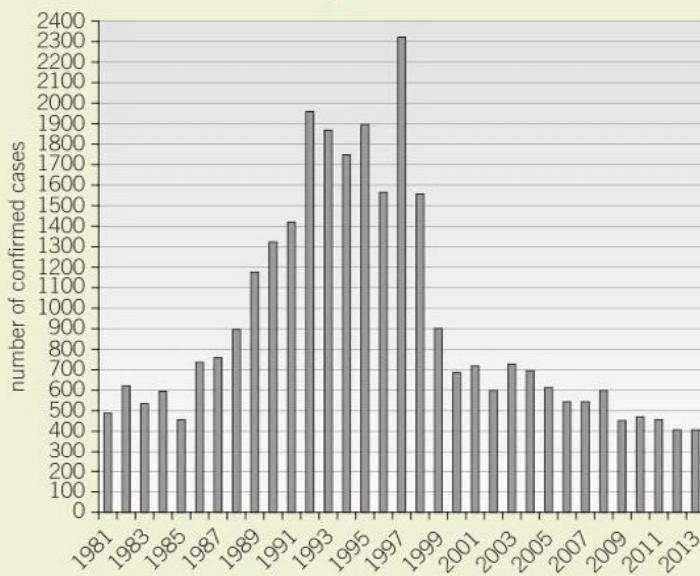
Type of pathogen
bacterium
virus
protist
fungus

[3 marks]

*Salmonella* food poisoning is caused by ingesting food contaminated with the pathogen.

**Figure 1** shows the number of laboratory confirmed cases of *Salmonella* food poisoning in Wales from 1981 to 2013.

**Figure 1**



**01.2** In which year was the highest number of confirmed cases of *Salmonella*? [1 mark]

**01.3** How many confirmed cases were there in that year? [1 mark]

**01.4** Suggest **one** reason why this value may not be the total number of *Salmonella* cases in Wales that year. [1 mark]

**01.5** The high number of cases that year was due to people eating eggs from infected chickens. The number of cases of *Salmonella* has rapidly decreased since then. Suggest **two** reasons for the decrease. [2 marks]

**02**

Rose black spot is a fungal infection of roses.

**Figure 2** shows a rose leaf infected with the rose black spot fungus.

**Figure 2**

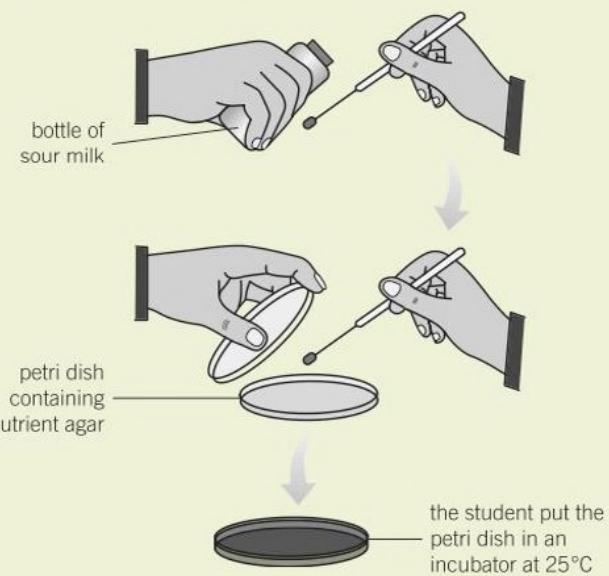


Black spots appear on the leaves. The leaves may turn yellow and drop from the plant.

**02.1** Explain how rose black spot disease might affect the growth of a rose bush. [3 marks]

**02.2** Suggest **two** things a gardener could do to kill the fungus and reduce the chance of another rose black spot infection. [2 marks]

**03** A student transferred some sour milk from a bottle to a Petri dish containing nutrient agar. The student then incubated the Petri dish.



Describe and explain **two** precautions the student should take so that only bacteria from the milk grow on the nutrient agar. [4 marks]

AQA, 2012

# 6 Preventing and treating disease

## 6.1 Vaccination

### Learning objectives

After this topic, you should know:

- how your immune system works
- how vaccination protects you against disease.



**Figure 1** No one likes having a vaccination very much – but they save millions of lives around the world every year!

Every cell has unique proteins on its surface called antigens. The antigens on the microorganisms that get into your body are different to the ones on your own cells. Your immune system recognises that they are different.

Your white blood cells then make specific antibodies, which join up with the antigens and inactivate or destroy that particular pathogen.

Some of your white blood cells (the memory cells) 'remember' the right antibody needed to destroy a particular pathogen. If you meet that pathogen again, these memory cells can make the same antibody very quickly to kill the pathogen, so you become immune to the disease.

The first time you meet a new pathogen you get ill because there is a delay while your body sorts out the right antibody needed. The next time, your immune system destroys the invaders before they can make you feel unwell.

### Vaccination

Some pathogens, such as meningitis, can make you seriously ill very quickly. In fact, you can die before your body manages to make the right antibodies. Fortunately, you can be protected against many of these serious diseases by vaccination (also known as immunisation).

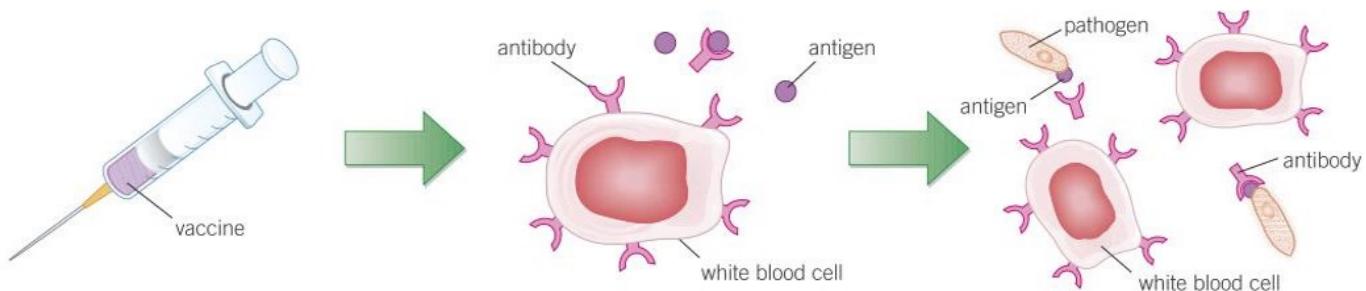
Immunisation involves giving you a **vaccine** made of a dead or inactivated form of a disease-causing microorganism. It stimulates your body's natural immune response to invading pathogens.

A small amount of dead or inactive forms of a pathogen is introduced into your body. This stimulates the white blood cells to produce the antibodies needed to fight the pathogen and prevent you from getting ill. Then, if you meet the same, live pathogen, your white blood cells can respond rapidly. They can make the right antibodies just as if you had already had the disease, so that you are protected against it.

Doctors use vaccines to protect us both against bacterial diseases, such as tetanus and diphtheria, and viral diseases such as polio, measles and mumps. For example, the MMR vaccine protects against measles, mumps, and rubella. Vaccines have saved millions of lives around the world. One disease – smallpox – has been completely wiped out by vaccinations. Doctors hope polio will also disappear in the next few years.

### Study tip

High levels of antibodies do not stay in your blood forever. Immunity is *not* a constantly high level of antibodies to a disease. It is the ability of your white blood cells to produce the right antibodies quickly, as a result of memory cells, if you are re-infected by a disease.



Small amounts of dead or inactive pathogen are put into your body, often by injection.

The antigens in the vaccine stimulate your white blood cells into making antibodies. The antibodies destroy the antigens without any risk of you getting the disease.

You are immune to future infections by the pathogen. That's because your body can respond rapidly and make the correct antibody as if you had already had the disease.

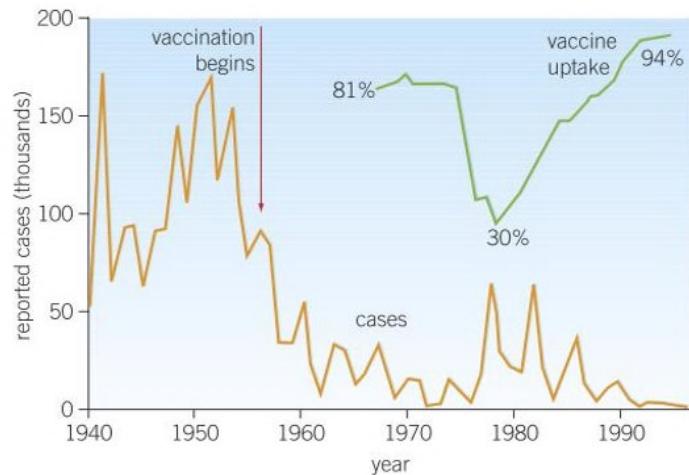
**Figure 2** This is how vaccination protects you against dangerous infectious diseases

## Herd immunity

If a large proportion of the population is immune to a disease, the spread of the pathogen in the population is very much reduced and the disease may even disappear. This is known as herd immunity. If, for any reason, the number of people taking up a vaccine falls, the herd immunity is lost and the disease can reappear. This is what happened in the UK in the 1970s when there was a scare about the safety of the whooping cough vaccine. Vaccination rates fell from over 80% to around 30% (Figure 3). In the following years, thousands of children got whooping cough again and a substantial number died. Yet the vaccine was as safe as any medicine.

Eventually people realised this and enough children were vaccinated for herd immunity to be effective again. There are global vaccination programmes to control a number of diseases, including tetanus in mothers and new-born babies, polio, and measles. The World Health Organisation want 95% of children to have two doses of measles vaccine to give global herd immunity. Current global figures show that 85% of children get the first dose and 56% get the second. It will take money and determination to get global herd immunity against a range of different diseases, but the advantages both to individuals and to global economies are huge.

- 1 **a** Describe what an antigen is. [1 mark]
- b** Describe what an antibody is. [1 mark]
- c** Give an example of one bacterial and one viral disease that you can be immunised against. [2 marks]
  
- 2 Explain, using diagrams if they help you:
  - a** how the immune system of your body works [5 marks]
  - b** how vaccines use your natural immune system to protect you against serious diseases. [5 marks]
  
- 3 Explain why vaccines can be used against both bacterial and viral diseases. [5 marks]



Source: Open University

**Figure 3** Graph showing the effect of the whooping cough scare on both uptake of the vaccine and the number of cases of the disease

## Key points

- If a pathogen enters the body the immune system tries to destroy the pathogen.
- Vaccination involves introducing small amounts of dead or inactive forms of a pathogen into your body to stimulate the white blood cells to produce antibodies. If the same live pathogen re-enters the body, the white blood cells respond quickly to produce the correct antibodies, preventing infection.
- If a large proportion of the population is immune to a pathogen, the spread of the pathogen is much reduced.

# B6.2 Antibiotics and painkillers

## Learning objectives

After this topic, you should know:

- what medicines are and how some of them work
- that painkillers and other medicines treat disease symptoms but do not kill pathogens
- the ways in which antibiotics can and cannot be used.



**Figure 1** Giving this baby a painkiller will make him feel better, but he will not actually get better any faster as a result

## Study tip

Don't confuse antiseptics, antibiotics and antibodies.

- Antiseptics kill microorganisms in the environment.
- Antibiotics kill bacteria (*not viruses*) in the body.
- Antibodies are made by white blood cells to destroy pathogens (both bacteria *and* viruses).

When you have an infectious disease, you generally take medicines that contain useful drugs. Often the medicine doesn't affect the pathogen that is causing the problems – it just eases the symptoms and makes you feel better.

## Treating the symptoms

Drugs such as aspirin and paracetamol are very useful painkillers. When you have a cold, they will help relieve your headache and sore throat. On the other hand, they will have no effect on the viruses that have entered your tissues and made you feel ill.

Many of the medicines you can buy at a chemists or supermarket relieve your symptoms but do not kill the pathogens, so they do not cure you any faster. You have to wait for your immune system to overcome the pathogens before you actually get well again.

## Antibiotics – drugs to cure bacterial diseases

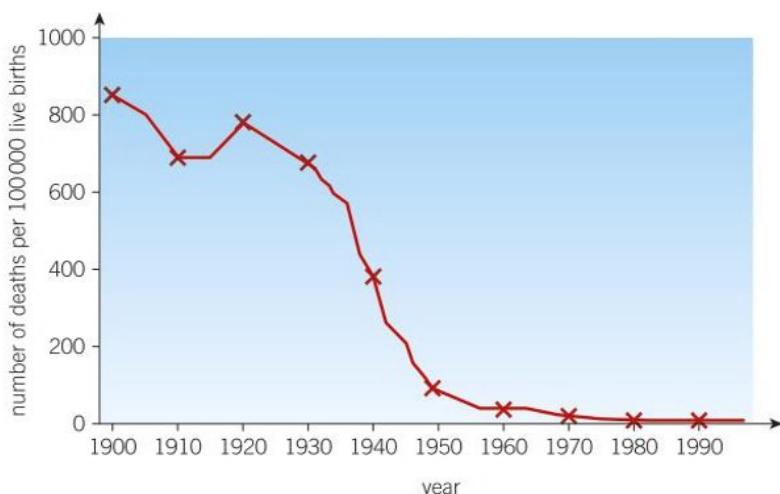
Drugs that make you feel better are useful, but in some cases what you really need are drugs that can cure you. You can use antiseptics and disinfectants to kill bacteria outside the body, but they are far too poisonous to use inside your body. They would kill you and your pathogens at the same time.

The drugs that have really changed the treatment of communicable diseases are antibiotics. These are medicines that can work inside your body to kill bacterial pathogens. The impact of antibiotics on deaths from communicable diseases has been enormous. Antibiotics first became widely available in the 1940s. They were regarded as wonder drugs. For example, the number of women who died of infections in the first days after giving birth dropped dramatically (Figure 2).

## How antibiotics work

Antibiotics, such as penicillin, work by killing the bacteria that cause disease whilst they are inside your body. They damage the bacterial cells without harming your own cells. Bacterial diseases that killed millions of people in the past can now be cured using antibiotics. They have had an enormous effect on our society.

If you need antibiotics, you usually take a pill or syrup, but if you are very ill antibiotics may be put straight into your bloodstream. This makes sure that they reach the pathogens in your cells as quickly as possible. Some antibiotics kill a wide range of bacteria. Others are very specific and only work against particular bacteria. It is important that the right antibiotic is chosen and used. Specific bacteria should be treated with the specific antibiotic that is effective against them.



**Figure 2** The introduction of antibiotics in the 1940s had an enormous impact on deaths from maternal septicaemia

Unfortunately, antibiotics are not the complete answer to the problem of infectious diseases:

- Antibiotics cannot kill viral pathogens so they have no effect on diseases caused by viruses. Viruses reproduce inside the cells of your body. It is extremely difficult to develop drugs that will kill the viruses without damaging the cells and tissues of your body at the same time.
- Strains of bacteria that are resistant to antibiotics are evolving. This means that antibiotics which used to kill a particular type of bacteria no longer have an effect, so they cannot cure the disease. There are some types of bacteria that are resistant to all known antibiotics. The emergence of antibiotic-resistant strains of bacteria is a matter of great concern. Unless scientists can discover new antibiotics soon, we may no longer be able to cure bacterial diseases. This means that many millions of people in the future will die of bacterial diseases that we can currently cure. You will learn more about the discovery of antibiotics in Topic B6.4.

- Describe the main difference between drugs such as paracetamol and drugs such as penicillin. [2 marks]
- Explain why it is more difficult to develop medicines against viruses than it has been to develop antibiotics. [4 marks]
- Use Figure 2 to answer the following.
  - How many women died in childbirth or shortly afterwards in 1930, 1940, and 1950 from maternal septicaemia. [3 marks]
  - Calculate the percentage fall or rise in the death rates of mothers around the time of birth in:
    - 1930 and 1940 [3 marks]
    - 1940 and 1950. [3 marks]
  - Suggest reasons for these observations. [3 marks]
  - Based on this evidence, explain why the emergence of antibiotic-resistant bacteria is such a cause of concern. [3 marks]



**Figure 3** Penicillin was the first antibiotic. Now there are many different ones that kill different types of bacterium. Here, several different antibiotics are being tested on an agar plate.

### Synoptic links

You will learn more about the development of antibiotic resistance in bacteria in Topic B15.8.

### Key points

- Painkillers and other medicines treat the symptoms of disease but do not kill the pathogens that cause it.
- Antibiotics cure bacterial diseases by killing the bacterial pathogens inside your body.
- The use of antibiotics has greatly reduced deaths from infectious diseases.
- The emergence of strains of bacteria resistant to antibiotics is a matter of great concern.
- Antibiotics do not destroy viruses because viruses reproduce inside the cells. It is difficult to develop drugs that can destroy viruses without damaging your body cells.



# B6.3 Discovering drugs

## Learning objectives

After this topic, you should know:

- some of the drugs traditionally extracted from plants
- how penicillin was discovered
- how scientists look for new drugs.



**Figure 1** Chewing on the glands of beaver tail brought unexplained relief to people in the days before clean effective painkillers such as aspirin or paracetamol were available. The tail glands contained concentrated pain-relieving chemicals from willow bark chewed by the beaver

Traditionally drugs were extracted from plants or microorganisms such as moulds. In ancient Egypt mouldy bread was used on septic wounds, perhaps an early form of antibiotic treatment. Now scientists often adapt chemicals from microorganisms, plants, and animals to make more effective drugs.

## Drugs from plants

There are a number of drugs used today that are based on traditional medicines extracted from plants.

Digitalis is one of several drugs extracted from foxgloves, and the drug digoxin is another. They have been used since the 18th century to help strengthen the heartbeat. There are many more modern drugs but doctors still use digoxin, especially for older patients with heart problems. Large amounts of these chemicals can act as poisons.

The painkiller aspirin originates from a compound found in the bark of willow trees. The anti-inflammatory and pain-relieving properties were first recorded in 400BC. In 1897, Felix Hoffman synthesised acetyl salicylic acid (aspirin), which not only relieves pain and inflammation better than willow bark but has fewer side effects. Aspirin is still commonly used to treat a wide range of health problems.

## Drugs from microorganisms – discovering penicillin

In the early 20th century, scientists were looking for chemicals that might kill bacteria and cure infectious diseases. In 1928, Alexander Fleming was growing bacteria for study purposes. He was rather careless, often leaving the lids off his culture plates – health and safety procedures were not as good in those days.

After one holiday, Fleming saw that lots of his culture plates had mould growing on them. He noticed a clear ring in the jelly around some of the spots of mould and realised something had killed the bacteria covering the gel. Fleming recognised the importance of his observations. He called the substance that killed bacteria 'penicillin' after the *Penicillium* mould that produced it. He tried unsuccessfully for several years to extract an active juice from the mould before giving up and moving on to other work.

About 10 years after Fleming's discovery, Ernst Chain and Howard Florey set about trying to extract penicillin, and they succeeded. They gave some penicillin to a man dying of a blood infection and he recovered almost miraculously – until the penicillin ran out. Even though their patient died, Florey and Chain demonstrated that penicillin could cure bacterial infections in people. Eventually, working with the company Pfizer in the USA, Florey and Chain made penicillin on an industrial scale, producing enough to supply the demands of World War II. It is still used today.

## Medicines for the future

There is a continuing drive to find new medicines but it is difficult. For example, it is not easy to find chemicals that kill bacteria without damaging human cells. Most drugs are now synthesised by research chemists working in the pharmaceutical industry using chemical banks and computer models. However, the starting point may still be a chemical extracted from a plant or microorganism. Compounds showing promise as antibiotics can be modified to produce more powerful molecules that can be synthesised easily and cheaply.

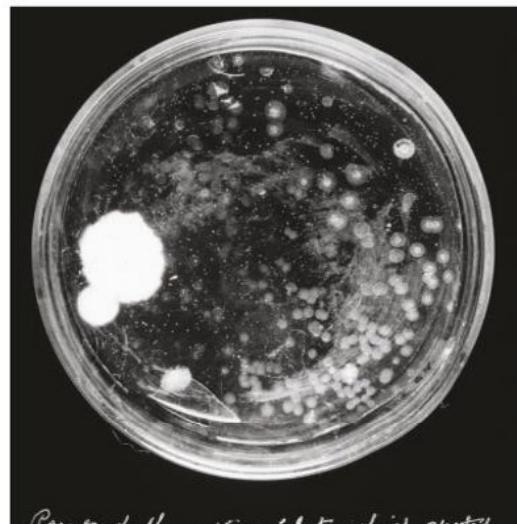
For example, the noni fruit is widely used in traditional medicine in Costa Rica and many other countries to treat both infections and non-communicable diseases. People have also used it for food and drink for centuries with no apparent problems. Recent research shows that it has antibiotic properties. More research is taking place to see if this traditional healing plant might be the source of new antibiotics or other medicines.



**Figure 3** The noni fruit looks strange and smells stranger, but will it provide us with medicines for the future?

Scientists are also collecting soil samples globally and searching for microorganisms to produce a new antibiotic against antibiotic-resistant bacteria. Only about 1% of soil microorganisms can be cultured in the lab. Scientists have developed a special unit that enables them to grow microorganisms in the soil in a controlled way. Using this technology, in 2015 they announced a completely new type of antibiotic from some soil bacteria. In tests so far, this antibiotic has destroyed all bacteria including MRSA and other antibiotic resistant pathogens. It worked in mice – will it work in humans?

- 1 Describe how Alexander Fleming discovered penicillin. [3 marks]
- 2 Suggest reasons for using synthetic forms of drugs rather than using plant extracts directly. [4 marks]
- 3 Explain the advantages and disadvantages of looking for new antibiotic compounds in living organisms based on the example of the noni fruit.  [6 marks]



Print of the culture plate which started the work on Penicillium (25 years old and rather dried up) AF

**Figure 2** Alexander Fleming was on the lookout for something that would kill bacteria. Because he noticed the effect of this mould on his cultures, millions of lives have been saved around the world

## Synoptic links

You will learn more about the development of antibiotic resistant bacteria in Topic B15.8.

## Key points

- Traditionally drugs were extracted from plants, for example, digitalis, or from microorganisms, for example, penicillin.
- Penicillin was discovered by Alexander Fleming from the *Penicillium* mould.
- Most new drugs are synthesised by chemists in the pharmaceutical industry. However, the starting point may still be a chemical extracted from a plant.



# B6.4 Developing drugs

## Learning objectives

After this topic, you should know:

- the stages involved in testing and trialling new drugs
- why testing new drugs is so important.



**Figure 1** The development of a new medicine costs millions of pounds and involves many people and lots of equipment

New medicines are being developed all the time, as scientists and doctors try to find ways of curing more diseases. Scientists test new medicines in the laboratory. Every new medical treatment has to be extensively tested and trialled in a series of stages before it is used. This process makes sure that it works well and is as safe as possible.

A good medicine is:

- Effective – it must prevent or cure a disease or at least make you feel better.
- Safe – the drug must not be too toxic (poisonous) or have unacceptable side effects for the patient
- Stable – you must be able to use the medicine under normal conditions and store it for some time.
- Successfully taken into and removed from your body – it must reach its target and be cleared from your system once it has done its work.

## Developing and testing a new drug

When scientists research a new medicine they have to make sure all these conditions are met. It can take up to 12 years to bring a new medicine into your doctor's surgery and costs around £1700 million, including failures and capital costs.

Researchers target a disease and make lots of possible new drugs. These are tested in the laboratory to find out if they are toxic (toxicity) and if they seem to do their job (efficacy). In the laboratory they are tested on cells, tissues, and even whole organs. Many chemicals fail at this stage.

The small numbers of chemicals, which pass the earlier tests, are then laboratory tested on animals, to find out how they work in a whole living organism. It also gives information about possible doses and side effects. The tissues and animals are used as models to predict how the drugs may behave in humans.

Up to this point the chemicals are undergoing **preclinical testing**. This always takes place in the laboratory using cells, tissues, and live animals.

Drugs that pass animal testing move on to **clinical trials**. Clinical trials use healthy volunteers and patients. First, very low doses are given to healthy people to check for side effects. If the drug is found to be safe, it is tried on a small number of patients to see if it treats the disease. If it seems to be safe and effective, bigger clinical trials take place to find the optimum dose for the drug.

If the medicine passes all the legal tests, it is licenced so your doctor can prescribe it. Its safety will be monitored for as long as it is used.

## Study tips

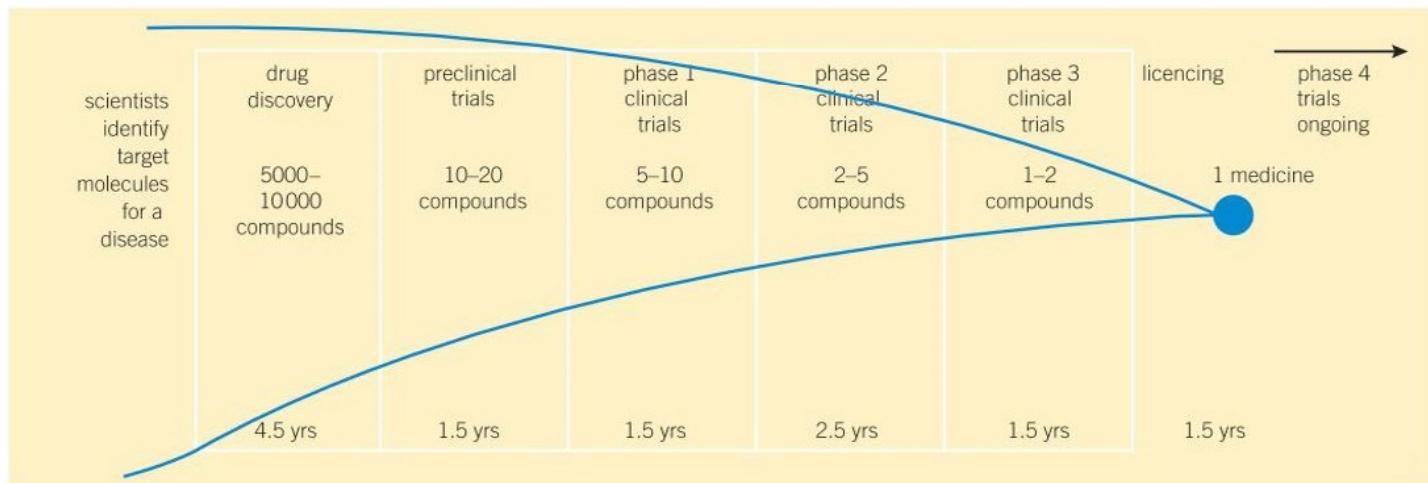
Make sure you are clear that new drugs are extensively tested for:

- efficacy
- toxicity
- dosage.

## Double blind trials

In human trials, scientists use a double blind trial to see just how effective the new medicine is. A group of patients with the target disease agree to take part in the trials. Some are given a **placebo** that does not contain the drug and some are given the new medicine. Patients are randomly allocated to the different groups. Then neither the doctor nor the patients know who has received the real drug or the placebo until the trial is complete. The patients' health is monitored carefully.

Often the placebo will contain a different drug that is already used to treat the disease. This means the patient is not deprived of treatment whilst taking part in the trial.



**Figure 2** An enormous number of chemicals start the selection process but few actually become a new, useful medicine

## Publishing results

The results of drug tests and trials, like all scientific research, are published in journals after they have been scrutinised in a process of peer review. This means other scientists working in the same area can check the results over, helping to prevent false claims. National bodies such the National Institute for Health and Care Excellence (NICE) look at the published results of drugs trials and decide which drugs give good value for money and should be prescribed by the NHS.

- 1 All new drugs are extensively tested for efficacy, toxicity, and dosage. Define these three terms. [3 marks]
- 2 **a** Testing a new medicine costs a lot of money and can take up to 12 years. Draw a flow chart to show the main stages in testing new drugs. [6 marks]
- b** Explain why an active drug is often used as the placebo in a clinical trial instead of a sugar pill that has no effect. [3 marks]
- 3 Florey and Chain tried penicillin on a human volunteer without preclinical trials. Thalidomide was used without any proper testing and caused limb deformities in developing foetuses. The outcomes were very different. Explain the need for full trialling of all drugs and consider how and why the process has changed over time. [6 marks]

## Key points

- New medical drugs are extensively tested for efficacy, toxicity, and dosage.
- New drugs are tested in the laboratory using cells, tissues, and live animals.
- Preclinical testing of new drugs takes place in a laboratory on cells, tissues, and live animals. Clinical trials use healthy volunteers and patients. Low doses are used to test for safety, followed by higher doses to test for optimum dose.
- In double blind trials, some patients are given a placebo.

# B6.5 Making monoclonal antibodies

## Learning objectives

After this topic, you should know:

- how monoclonal antibodies are produced
- how monoclonal antibodies are used.

Imagine combining cells from mice or people and cancer cells to form a new type of cell. Then using those new cells in human and animal medicine and in the diagnosis of plant diseases. This might sound far-fetched or even dangerous. However, scientists and doctors are finding more and more ways of using these unusual cells, known as **hybridomas**.

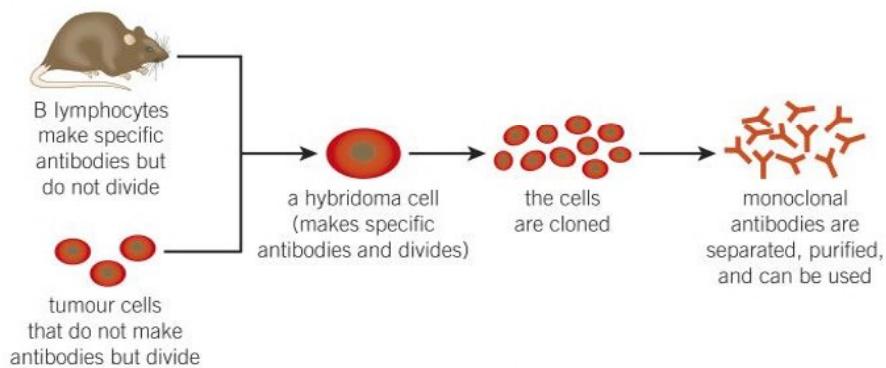
## Making monoclonal antibodies

Monoclonal antibodies, like vaccinations, are a form of medical treatment that relies on the immune system. Monoclonal antibodies are proteins that are produced to target particular cells or chemicals in the body. Some white blood cells known as lymphocytes make antibodies but cannot divide. Tumour cells do not usually make antibodies but they can divide rapidly to make a clone of cells.

All mammals, including mice, produce lymphocytes. Scientists combine mice lymphocytes (that have been stimulated to make a particular antibody) with a type of tumour cell to make a cell called a hybridoma. Single hybridoma cells divide to make a large number of identical cells that all produce the same antibodies (Figure 1). These antibodies are collected and purified. They are monoclonal antibodies – antibodies produced from a single clone of cells. More recently scientists have combined the mice cells with human cells as well to produce monoclonal antibodies that are less likely to be rejected by human cells.

## Synoptic links

You can remind yourself about the immune system and antibodies in Topic B5.9, about how cancer cells grow and develop in Topic B7.2, and about clones of cells in Topic B2.1.



**Figure 1** The production of monoclonal antibodies

## Using monoclonal antibodies

Antigens are protein molecules that are often found on the surface of cells, although free protein molecules can also act as antigens. The monoclonal antibodies produced from a single clone of cells are specific to one binding site on one specific antigen. This antigen might be found only on specific types of cell in the body, or it might be a specific chemical. Because the monoclonal antibodies only target and bind to one specific antigen, they can then be used in a number of ways.

- Pregnancy tests – these rely on monoclonal antibodies that bind to the hormone human chorionic gonadotropin (HCG) that is made in the early stages of pregnancy.

Tiny amounts of the hormone are passed out of the body in the urine. Monoclonal antibodies

in the pregnancy test bind to the hormone if it is present, and this is used to produce the colour change that signals a positive result.

- Diagnosis of disease – monoclonal antibodies are made to bind to specific antigens found on pathogens, or on blood clots or on cancer cells. The monoclonal antibodies may also carry markers that make it easy for doctors to see where they have built up. This allows doctors to detect problems before they are seriously affecting a patient's health. For example, the blood test for prostate cancer uses monoclonal antibodies to bind to prostate-specific antigens. Monoclonal antibodies are becoming increasingly important in the detection of plant, animal, and human diseases.
- Measuring and monitoring – monoclonal antibodies are used in hospitals and laboratories to measure or monitor the levels of hormones and other chemicals in the blood. For example, screening donated blood for HIV infection, detecting drugs that have been used illegally by athletes, and detecting infections such as syphilis.
- Research – research scientists use monoclonal antibodies to locate or identify specific molecules in a cell or tissue. Scientists produce the monoclonal antibodies linked to a molecule of a fluorescent dye. When the monoclonal antibodies bind to the desired molecules, scientists can see what has happened by observing the build-up of fluorescence.
- Treating disease – you will learn more about how monoclonal antibodies are used to treat disease in Topic B6.6.



**Figure 2** The monoclonal antibodies in a pregnancy test are so sensitive to the presence of HCG that the test can be taken on the first day of a missed period

### Go further

Monoclonal antibodies are used to produce Enzyme-Linked Immunosorbent Assays, or ELISAs. ELISAs are used to detect antibodies or pathogens in a sample. They are increasingly being used to detect disease in animals and plants. They also have many research uses.

### Key points

- Monoclonal antibodies are produced from a single clone of cells. Each type is specific to one binding site on a specific protein antigen so they can target specific cells in the body or specific chemicals.
- Monoclonal antibodies are produced by stimulating mouse lymphocytes to make a specific antibody. Large amounts of the specific monoclonal antibody can be collected and purified.
- Monoclonal antibodies are used:
  - for diagnosis in pregnancy tests
  - in labs to measure levels of hormones and other chemicals in the blood to detect pathogens for research
  - to identify or locate specific molecules in cells or tissue.

- a Define a clone. [1 mark]  
b Define an antibody. [1 mark]  
c Define a monoclonal antibody. [1 mark]
- a Describe a hybridoma cell. [3 marks]  
b Explain the importance of hybridoma cells in the production of monoclonal antibodies. [3 marks]
- Explain how monoclonal antibodies have revolutionised the diagnosis of pregnancy. [4 marks] 

# B6.6 Uses of monoclonal antibodies

## Learning objectives

After this topic, you should know:

- some uses of monoclonal antibodies
- advantages and disadvantages of using monoclonal antibodies.

At the beginning of the 20th century, Nobel Prize winner Paul Ehrlich was the first scientist to imagine a 'magic bullet' – a drug precisely targeted at a pathogen or disease. When monoclonal antibodies were first developed in 1975, doctors and scientists thought they had found the magic bullet.

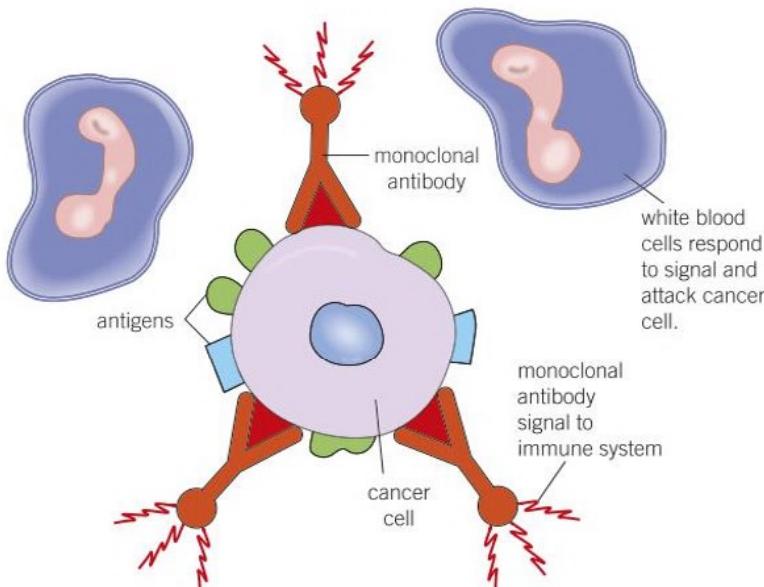
## Treatment of disease

Because monoclonal antibodies target a specific type of cell or a specific chemical, scientists and doctors are looking at ways to use them in the treatment of very specific diseases. Many types of cancer are still not easy to treat, and scientists are working hard to develop treatments using different monoclonal antibodies that will target specific cancers. They are increasingly successful. Currently there are three different ways of using monoclonal antibodies to treat cancers. Each has produced some cancer treatments that are being used and many more are in clinical trials. They include:

- Direct use of monoclonal antibodies to trigger the immune system to recognise, attack, and destroy cancer cells (Figure 1).

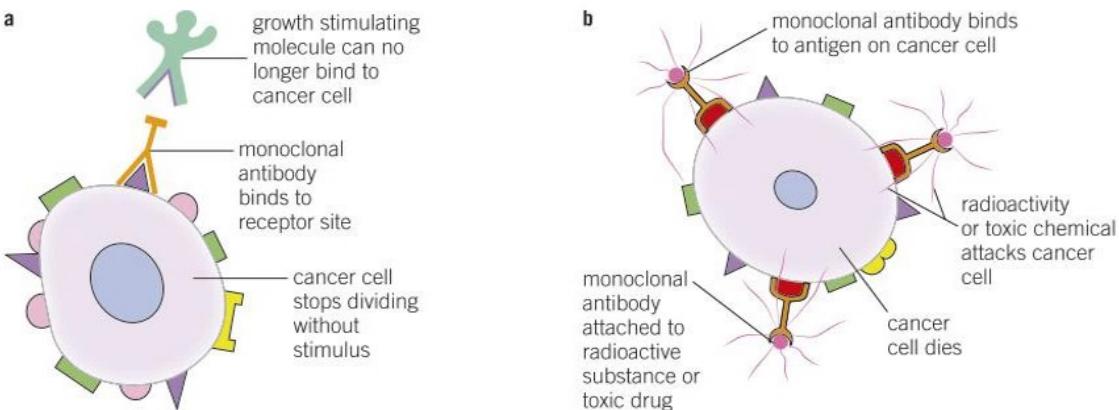
## Synoptic links

You can remind yourself about the immune system and antibodies in Topic B5.9, how cancer cells grow and develop in Topic B7.2, and about clones of cells in Topic B2.3.



**Figure 1** Monoclonal antibodies can trigger the immune system by making cancer cells more noticeable

- Using monoclonal antibodies to block receptors on the surface of cancer cells and so stop the cells growing and dividing (Figure 2a).
- Monoclonal antibodies can be used to carry toxic drugs or radioactive substances for radiation therapy, or chemicals that stop cells growing and dividing to attack the cancer cells directly, without harming other cells in the body (Figure 2b).



**Figure 2** Monoclonal antibodies may bind to receptors on cancer cells, removing the stimulus to grow and divide (a) or may carry drugs or radioactive therapies to cancer cells (b)

## Advantages and disadvantages of monoclonal antibodies

One of the biggest potential advantages of using monoclonal antibodies is that they only bind to the specific diseased or damaged cells that need treatment. Healthy cells are not affected at all. In contrast, conventional drug treatment is carried all around the body in the blood and can have a devastating effect on healthy cells as well as, for example, cancer cells. Radiotherapy treatment for cancer is targeted on the area of the body affected by the tumour but still usually affects the healthy tissue in that area as well. Another advantage is that the specificity of monoclonal antibodies means that they could be used to treat a wide range of conditions. Although at the moment monoclonal antibodies are very expensive to develop, potentially they could become cheaper to develop than conventional drugs, because all the treatments will be based on a tested technology.

Monoclonal antibody treatments are not yet as widely used or as successful as everyone hoped when they were first developed almost 40 years ago. Initially they created more side effects than expected. This was partly due to the use of mouse cells only in the formation of the hybridoma cells. The monoclonal antibodies produced were mouse antibodies, and they triggered an immune response in humans. This held back research. Now developments such as the production of mouse-human hybrid cells and the use of fractions of antibodies to carry drugs to target cells are reducing side effects. Also, doctors are now prepared for side effects and can treat the symptoms.

Producing the right monoclonal antibodies and attaching them to drugs and other compounds proved more difficult than expected. The development of more skills and technologies now means monoclonal antibodies are being used in more and more different ways. They may yet end up as the magic bullets of medicine – or at least as part of the bullet.

### Key points

- Monoclonal antibodies are used in the treatment of diseases.
- They have been developed against the antigens on cancer cells.
- If a monoclonal antibody is bound to a radioactive substance, a toxic drug, or a chemical that stops cells growing and dividing, it will deliver the substance to the cancer cells without harming other cells in the body.
- Monoclonal antibodies have created more side effects than expected and are not yet as widely used as hoped when they were first developed.

- 1 Explain why people initially thought monoclonal antibodies could be used in the treatment of diseases such as cancer. [3 marks]
- 2 Explain the limitations that have been discovered in the use of monoclonal antibodies in human treatments and explain how they are being overcome. [6 marks]

# B6 Preventing and treating disease

## Summary questions

- 1 Vaccination uses your body's natural defence system to protect you against disease.
- Describe how vaccination works. [4 marks]
  - Produce a flow chart to show the process of developing active immunity after:
    - a natural infection [4 marks]
    - a vaccination. [4 marks]
  - There are vaccines for diseases such as diphtheria, polio, tetanus, and meningitis, but not for the common cold or tonsillitis. Suggest reasons for this. [2 marks]
- 2 Meningitis B and meningitis C are infections that can cause inflammation of the membranes around the brain and infection throughout the body (septicaemia). They are particularly serious in young children and teenagers, and can kill rapidly. Use Figure 1 to help you answer the questions below.

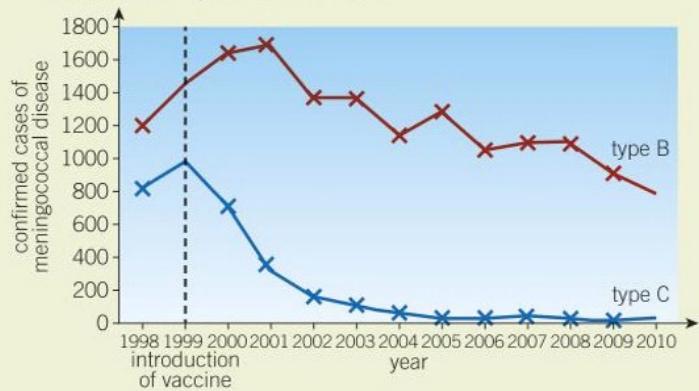


Figure 1 Annual confirmed cases of meningococcal disease 1998–2010

- How many cases of meningitis B and meningitis C were recorded in 1999? [2 marks]
- How many cases of meningitis B and meningitis C were recorded in 2005 and 2009? [2 marks]
- Suggest whether the introduction of the meningitis C vaccine in 1999 alone is responsible for the reduction in meningitis cases in the UK between 1998 and 2010. Explain your answer. [4 marks]
- Suggest one argument for and one argument against the introduction of a new vaccine against meningitis B. [2 marks]

- 3 a There are no medicines to cure measles, mumps or and rubella. What does this tell you about the pathogens that cause these diseases? [1 mark]
- b Suggest a medicine that might be used to make people feel more comfortable. [1 mark]
- c Doctors hope to get levels of MMR vaccination against measles, mumps, and rubella up to 95% of the population. Why is it important to get vaccination levels so high? [3 marks]
- 4 a Explain why new medicines need to be tested and trialled before doctors can use them to treat their patients. [5 marks]
- b Explain why the development of a new medicine is so expensive. [4 marks]
- c Do you think it would ever be acceptable to use a new medicine before all the trials are completed? Explain the reasoning behind your answer. [5 marks]

5 **Table 1** The number of new antibiotics introduced in the USA between 1983 and 2011

Year	Number of antibiotics introduced
1983–1987	16
1988–1992	14
1993–1997	10
1998–2002	7
2003–2007	5
2008–2011	2

- Use Table 1 to help you explain why there is such pressure to discover new medicines. [2 marks]
  - Some people argue for the conservation of biodiversity because the living world is a potential source of new medicines. Explain why this argument is not completely accurate. [4 marks]
  - Describe the main steps in the development of a new medicine to the point where it can be used by your local GP or hospital. [6 marks]
- 6 **H** Evaluate the use of monoclonal antibodies to treat diseases such as cancer. [6 marks]

## Practice questions

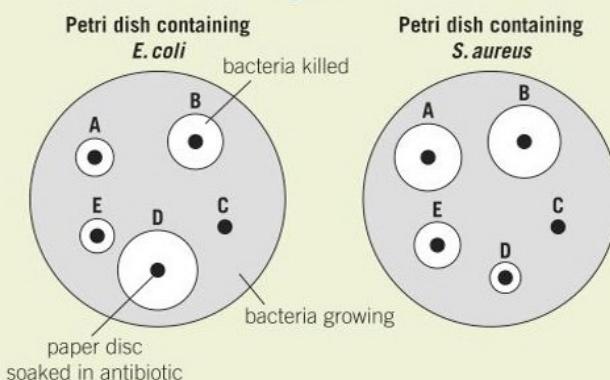
**01** A scientist investigated how effective five different antibiotics were at killing two types of bacteria, *E.coli* and *S.aureus*.

- The scientist grew the bacteria on agar in two different Petri dishes.
- He placed paper discs soaked in the 5 different antibiotic solutions, **A**, **B**, **C**, **D**, and **E** onto the agar.
- He used the same concentration of each antibiotic and the same sized paper discs.
- The Petri dishes were incubated at 25 °C for three days.

A clear area around the paper disc means that the antibiotic has killed the bacteria there.

The results are shown in **Figure 1**.

**Figure 1**



**01.1** Give one variable the scientist controlled. [1 mark]

Use the results shown in the diagram to help you to answer the following questions.

**01.2** Which antibiotic, **A**, **B**, **C**, **D**, or **E**, was the most effective at killing *E.coli*? [1 mark]

**01.3** Which antibiotic, **A**, **B**, **C**, **D**, or **E**, did not kill either *E.coli* or *S.aureus*? [1 mark]

**01.4** Which antibiotic, **A**, **B**, **C**, **D**, or **E**, would be the best to use to kill both *E.coli* and *S.aureus*? Give a reason for your answer. [2 marks]

**01.5** MRSA is a strain of *S.aureus*. MRSA cannot be killed by most antibiotics.

Use the correct word from the box to complete the sentence.

immune

powerful

resistant

Bacteria that cannot be killed by antibiotics

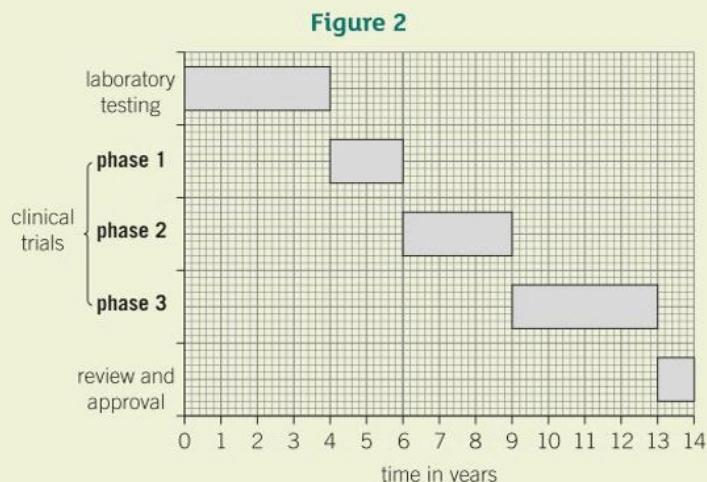
are .....

[1 mark]

AQA, 2013

**02** New drugs have to be tested before they can be sold.

**Figure 2** shows how much time the different stages of testing took for a new drug.



**02.1** How much more time did the clinical trials take than the laboratory testing? [1 mark]

**02.2** Apart from the time taken, what other difference is there between laboratory testing and clinical trials? [1 mark]

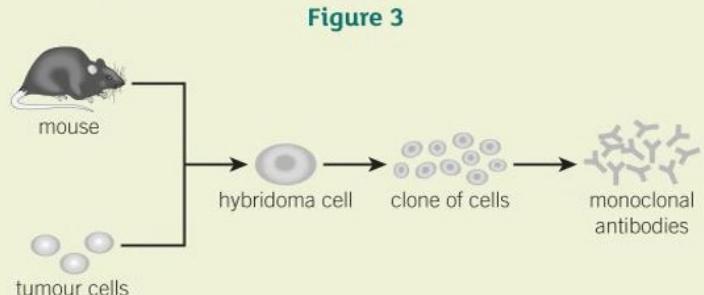
**02.3** During **Phase 1** clinical trials, the drug is tested on healthy volunteers using low doses. Suggest why **only** healthy volunteers and **only** low doses are used at this stage of drug testing. [2 marks]

**02.4** In **Phase 2** and **Phase 3** clinical trials, a double blind trial is usually done. Explain what a double blind trial is and why a double blind trial is good practice. [3 marks]

AQA, 2013

**H 03** Monoclonal antibodies are antibodies that target particular cells or chemicals in the body. They are used in diagnostic tests and in the treatment of some diseases.

**Figure 3** shows how monoclonal antibodies are produced.



Use **Figure 3** and your own knowledge to describe how monoclonal antibodies are produced. [6 marks]

# 7 Non-communicable diseases

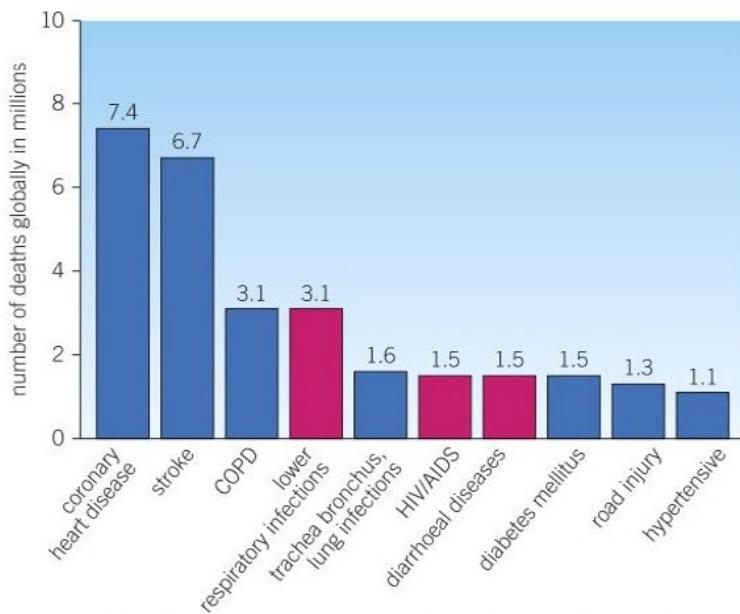
## 7.1 Non-communicable diseases

### Learning objectives

After this topic, you should know:

- what is meant by a non-communicable disease
- what a lifestyle factor is
- how scientists consider risk
- the human and financial costs involved
- what a causal mechanism is.

Only three of the top 10 killer diseases in the world in 2012 were communicable – lower respiratory tract infections such as pneumonia, HIV/AIDS, and diarrhoeal diseases. The other seven were non-communicable diseases. These are diseases that are not infectious and affect people as a result of their genetic makeup, their lifestyle, and factors in their environment.



**Figure 1** The leading causes of death globally in 2012 (WHO). Non-communicable diseases (blue bars) contribute to more deaths than communicable diseases (pink bars)

### Risk factors for disease

There are many risk factors for disease, including the genes you inherit from your parents and your age, which you cannot change. Risk factors for disease also include:

- aspects of your lifestyle such as smoking, lack of exercise, or overeating
- substances that are present in the environment or in your body such as ionising radiation, UV light from the sun, or second-hand tobacco smoke.

Certain lifestyle factors, or environmental substances, have been shown to increase your risk of developing particular diseases. Risk factors for non-communicable diseases vary from one disease to another and some may affect more than one disease. Examples of risk factors for a number of non-communicable diseases include diet, obesity, fitness levels, smoking, drinking alcohol, and exposure to **carcinogens** in the environment such as **ionising radiation**. We have the power to influence, change, or remove many of these risk factors.

## Causal mechanisms

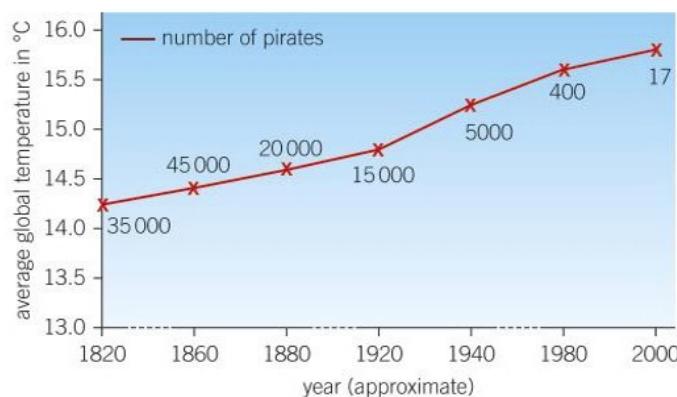
Scientists often see similarities in the patterns between non-communicable diseases such as cardiovascular disease or lung cancer with lifestyle factors such as lack of exercise or smoking. These similarities may suggest a link or relationship between the two, known as a **correlation**. However, a correlation does not prove that one thing is the cause of another (Figure 2).

It is useful to find correlations between lifestyle factors and particular diseases, but this is only the first step. Doctors and scientists then need to do lots of research to discover if there is a **causal mechanism**. A causal mechanism explains how one factor influences another through a biological process. If a causal mechanism can be demonstrated, there is a link between the two. For example, there is a clear causal link between smoking tobacco and lung cancer. Anyone can get lung cancer, but smoking increases that risk because you take carcinogens into your lungs.

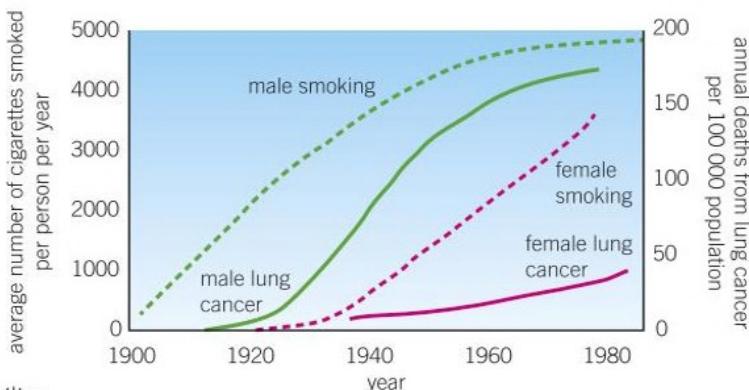
## The impact of non-communicable disease

Every serious disease has a human impact on the individual affected and their family. It will often have a financial cost as well if a wage-earner becomes ill and cannot work. Local communities often bear the cost of supporting people who are ill, whether formally through taxes or informally by taking care of affected families.

Diseases cost nations huge sums of money both in the expense of treating ill people and in the loss of money earned when large numbers of the population are ill. The global economy suffers too, especially when diseases affect younger, working-age populations. Non-communicable diseases affect far more people than communicable diseases, so they have the greatest effect at both human and economic levels.



**Figure 2** Falling levels of piracy and rising global temperatures between the years 1820 and 2000 look to be closely linked on this very unscientific graph but the apparent correlation does not mean one causes the other



**Figure 3** This graph shows the number of deaths from lung cancer and the average number of cigarettes smoked. In the UK, 86% of lung cancer cases are linked to smoking

- 1 a What is a non-communicable disease? [1 mark]
- b Describe the main differences between a communicable disease and a non-communicable disease. [2 marks]
- 2 a From Figure 1, identify which of the 10 leading causes of death in the world is *not* a disease? [1 mark]
- b Approximately how many people died as a result of a non-communicable disease? [2 marks]
- c What percentage of people died as a result of a non-communicable disease? [2 marks]
- 3 Explain the difference between risk factors, correlations, and causal mechanisms.  [6 marks]

## Key points

- A non-communicable disease cannot be passed from one individual to another.
- Risk factors are aspects of a person's lifestyle, or substances present in a person's body or environment, that have been shown to be linked to an increased rate of a disease.
- For some non-communicable diseases, a causal mechanism for some risk factors has been proven, but not in others.

# B7.2 Cancer

## Learning objectives

After this topic, you should know:

- what a tumour is
- the difference between benign and malignant tumours
- how cancer spreads.

## Synoptic link

You learnt about mitosis and the cell cycle in Topic B2.1.

Cancer is a disease that affects people in many families. The cells in your body divide on a regular basis in a set sequence known as the cell cycle that involves several stages. A **tumour** forms when control of this sequence is lost and the cells grow in an abnormal, uncontrolled way.

## Tumour formation

Tumour cells do not respond to the normal mechanisms that control the cell cycle. They divide rapidly with very little non-dividing time for growth in between each division. This results in a mass of abnormally growing cells called a tumour (Figure 1). Some tumours are caused by communicable diseases. For example, the bacteria *Agrobacterium tumefaciens* can cause crown galls in plants, and the human papilloma virus (HPV) can cause cervical cancer in humans.

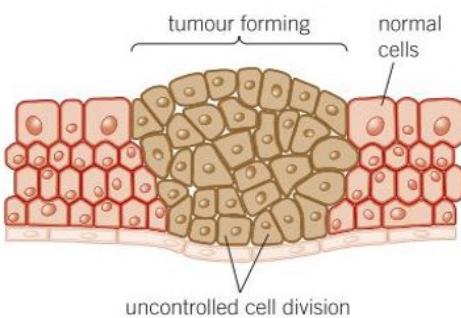


Figure 1 A tumour forms when there is uncontrolled cell division

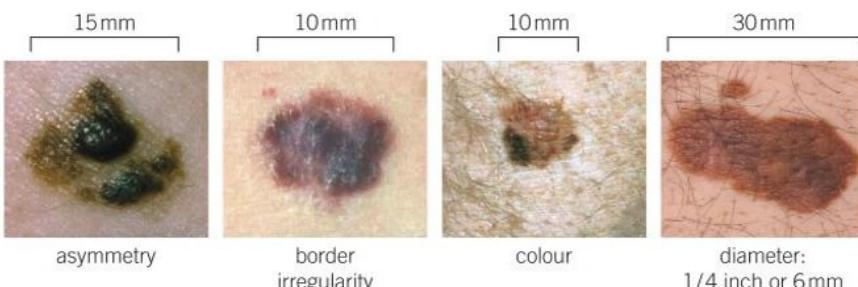
**Benign tumours** are growths of abnormal cells contained in one place, usually within a membrane. They do not invade other parts of the body but a benign tumour can grow very large, very quickly. If it causes pressure or damage to an organ, this can be life-threatening. For example, benign tumours on the brain can be very dangerous because there is no extra space for them to grow into.

**Malignant tumour cells** can spread around the body, invading neighbouring healthy tissues. A malignant tumour is often referred to as **cancer**. The initial tumour may split up, releasing small clumps of cells into the bloodstream or lymphatic system. They circulate and are carried to different parts of the body where they may lodge in another organ. Then they continue their uncontrolled division and form secondary tumours. Cancer cells not only divide more rapidly than normal cells, they also live longer. The growing tumour often completely disrupts normal tissues and, if left untreated, will often kill the person. Because of the way malignant tumours spread around the body, it can be very difficult to treat them.

## The causes of cancer

Scientists still do not understand what triggers the formation of many cancers, but some of the causes are well known.

- There are clear genetic risk factors for some cancers including early breast cancer and ovarian cancer.
- Most cancers are the result of mutations – changes in the genetic material. Chemicals such as asbestos and the tar found in tobacco smoke can cause mutations that trigger the formation of tumours. These cancer-causing agents are called carcinogens.
- Ionising radiation, such as UV light and X-rays, can also interrupt the normal cell cycle and cause tumours to form. For example, melanomas (Figure 2) appear when there is uncontrolled growth of pigment-forming cells in the skin as a result of exposure to UV light from the Sun.



**Figure 2** Melanomas are malignant tumours often triggered by exposure to UV radiation. Over 2000 people a year die from melanomas in the UK alone, so it is important to know the signs to look out for

- About 15% of human cancers are caused by virus infections. For example, cervical cancer is almost always the result of infection by HPV. Teenagers in the UK are now routinely vaccinated against the virus.

## Treating cancer

Because of the way cancer can spread through the body it can be difficult to treat. In recent years, treatments have become increasingly successful. Scientists are working hard to develop new treatments, and are also finding that combining some older treatments makes them more successful too. The two main ways we can treat cancer at the moment are:

- Radiotherapy, where the cancer cells are destroyed by targeted doses of radiation. This stops mitosis in the cancer cells but can also damage healthy cells. Methods of delivering different types of radiation in very targeted ways are improving cure rates.
- Chemotherapy, where chemicals are used to either stop the cancer cells dividing or to make them 'self-destruct'. There are many different types of chemotherapy and scientists are working to make them as specific to cancer cells as possible.

## Go further

There is more to the cancer story than mitosis out of control. Programmed cell death (known as apoptosis) normally gets rid of damaged or mutated cells but in tumours, apoptosis is sometimes suppressed. Signals from the cancer cells trigger the formation of blood vessels to feed the growing tumour. Scientists are now using DNA analysis of tumour cells to help them develop new cures and use the treatments they have as effectively as possible.

## Synoptic link

You learnt about the use of monoclonal antibodies to treat cancer in Topic B6.6.

- a** What is a tumour? [3 marks]
- b** Describe the difference between a benign tumour and a malignant tumour. [3 marks]
- c** Suggest ways in which both types of tumour can cause serious health problems. [4 marks]
- 2** One of the most common methods of treating cancers is chemotherapy. Chemotherapy drugs often affect other parts of the body, particularly hair follicles, skin cells, cells lining the stomach, and blood cells as well as the cancer cells.
  - Explain how the drugs used in chemotherapy might work. [2 marks]
  - Suggest reasons why healthy hair, skin, blood, and stomach lining cells are particularly badly affected by the drugs used to treat cancer. [4 marks]
- 3** Describe and explain the different treatments that are used to treat cancer. [4 marks]

## Key points

- Benign and malignant tumours result from abnormal, uncontrolled cell division.
- Benign tumours form in one place and do not spread to other tissues.
- Malignant tumour cells are cancers. They invade neighbouring tissues and may spread to different parts of the body in the blood where they form secondary tumours.
- Lifestyle risk factors for various types of cancer include smoking, obesity, common viruses, and UV exposure. There are also genetic risk factors for some cancers.

# B7.3 Smoking and the risk of disease

## Learning objectives

After this topic, you should know:

- how smoking affects the risk of developing cardiovascular disease
- how smoking affects the risk of developing lung disease and lung cancer
- the effect of smoking on unborn babies.

## Synoptic links

You can remind yourself of the structure of the breathing system in Topic B4.5 and of the way oxygen is carried around the body in Topic B4.1.



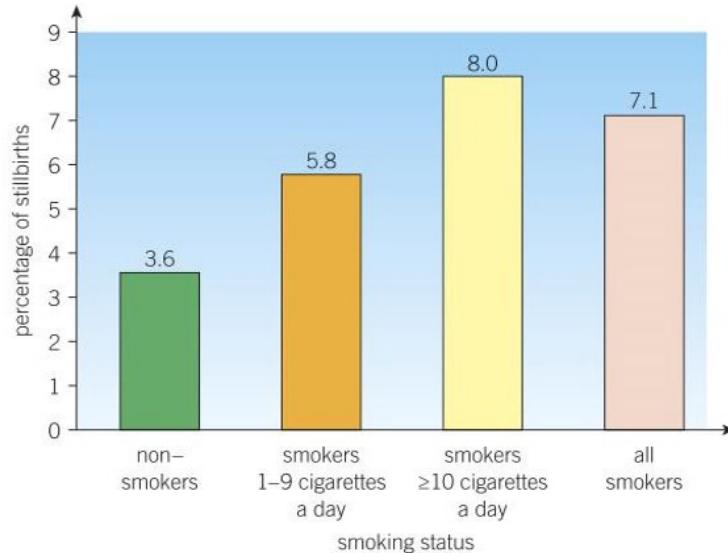
There are around 1.1 billion smokers world-wide, smoking around 6000 billion cigarettes each year, so smoking is big business. Every cigarette smoked contains tobacco leaves which, as they burn, produce around 4000 different chemicals that are inhaled into the throat, trachea, and lungs. At least 150 of these are linked to disease. Some of these chemicals are absorbed into the bloodstream to be carried around the body to the brain.

## Nicotine and carbon monoxide

Nicotine is the addictive but relatively harmless drug found in tobacco smoke. It produces a sensation of calm, well-being, and 'being able to cope' and this is why people like smoking. Unfortunately some of the other chemicals in tobacco smoke can cause lasting and often fatal damage to the body cells. Carbon monoxide is a poisonous gas found in tobacco smoke and it takes up some of the oxygen-carrying capacity of your blood. After smoking a cigarette, up to 10% of the blood will be carrying carbon monoxide rather than oxygen. This can lead to a shortage of oxygen, one reason why many smokers get more breathless when they exercise than non-smokers.

## Smoking during pregnancy

Oxygen shortage is a particular problem in pregnant women who smoke. During pregnancy a woman is carrying oxygen for her developing fetus as well as herself. If the mother's blood is carrying carbon monoxide, the fetus may not get enough oxygen to grow properly. This can lead to premature births, low birthweight babies and even stillbirths, where the baby is born dead. There are around 3500 stillbirths in the UK each year. Scientists estimate that around 20% result from the mother smoking during her pregnancy. In other words, 700 babies a year are born dead due to smoking.



**Figure 1** Smoking during pregnancy has a dramatic effect on the risk of stillbirths

## Carcinogens

The cilia in the trachea and bronchi that move mucus, bacteria, and dirt away from the lungs are anaesthetised by some of the chemicals in tobacco smoke. They stop working for a time, allowing dirt and pathogens down into the lungs and increasing the risk of infections. Mucus also builds up over time and causes coughing.

Other toxic compounds in tobacco smoke include tar. This is a sticky, black chemical that accumulates in the lungs, turning them from pink to grey. Along with other chemicals in the smoke, tar makes smokers much more likely to develop bronchitis (inflammation and infection of the bronchi). The build-up of tar in the delicate lung tissue can lead to a breakdown in the structure of the alveoli, causing chronic obstructive pulmonary disease (COPD). This reduces the surface area to volume ratio of the lungs, leading to severe breathlessness and eventually death.

Tar is also a carcinogen. It acts on the delicate cells of the lungs and greatly increases the risk of lung cancer developing. Tar also causes other cancers of the breathing system, for example, the throat, larynx, and trachea.

## Smoking and the heart

The chemicals in tobacco smoke also affect the heart and blood vessels. Scientists have data showing that smokers are more likely to suffer from cardiovascular problems than non-smokers (Table 1). They have also worked out the mechanisms that show it is a causal link, not just a correlation.

Smoking narrows the blood vessels in your skin, ageing it. Nicotine makes the heart rate increase whilst other chemicals damage the lining of the arteries. This makes coronary heart disease more likely, and it increases the risk of clot formation. The mixture of chemicals in cigarette smoke also lead to an increase in blood pressure. This combination of effects increases the risk of suffering cardiovascular disease including heart attacks and strokes.

- 1 a** Name three components of tobacco smoke. [3 marks]
- b** Explain what effect the three components you gave in part **a** have on the human body. [3 marks]
- 2 a** Display the data from Table 1 as a bar chart. [4 marks]
  - b** Describe what this data shows. [1 mark]
  - c** Describe possible causal mechanisms to explain the trend shown in the data. [3 marks]
- 3** Evaluate the information given that cigarette smoking increases the risk of developing lung cancer and explain how scientists think this effect is caused. [4 marks]
- 4** Many women continue to smoke when they are pregnant. Explain why smoking during pregnancy is so harmful. [5 marks]
- 5** Explain the human and financial cost of smoking to individuals and to nations around the world. [6 marks]

## Synoptic links

You can find out more about coronary heart disease and how it can be treated in Topic B4.3, and about the clotting of the blood in Topic B5.9.

**Table 1** *The number of deaths by cardiovascular disease (CVD) by average number of cigarettes smoked a day*

Cigarettes smoked per day	CVD deaths per 100 000 men per year
0	572
10 (range 1–14)	802
20 (range 15–24)	892
30 (range >24)	1025

## Key points

- Smoking can cause cardiovascular disease including coronary heart disease, lung cancer, and lung diseases such as bronchitis and COPD.
- A fetus exposed to smoke has restricted oxygen, which can lead to premature birth, low birthweight, and even stillbirth.

# B7.4 Diet, exercise, and disease

## Learning objectives

After this topic, you should know:

- the effect of diet and exercise on the development of obesity
- how diet and exercise affect the risk of developing cardiovascular disease
- that obesity is a risk factor for type 2 diabetes.

The evidence is building that your weight and the amount of exercise you take affects your risk of developing various diseases. These diseases can be life-changing and even life-threatening.

### Diet, exercise, and obesity

If you eat more food than you need, the excess is stored as fat. You need some body fat to cushion your internal organs and act as an energy store. However, over time regularly eating too much food will make you overweight and then obese.

Carrying too much weight is often inconvenient and uncomfortable. Far worse, obesity can lead to serious health problems, such as type 2 diabetes (high blood sugar levels, which are hard to control), high blood pressure, and heart disease.

### Exercise and health

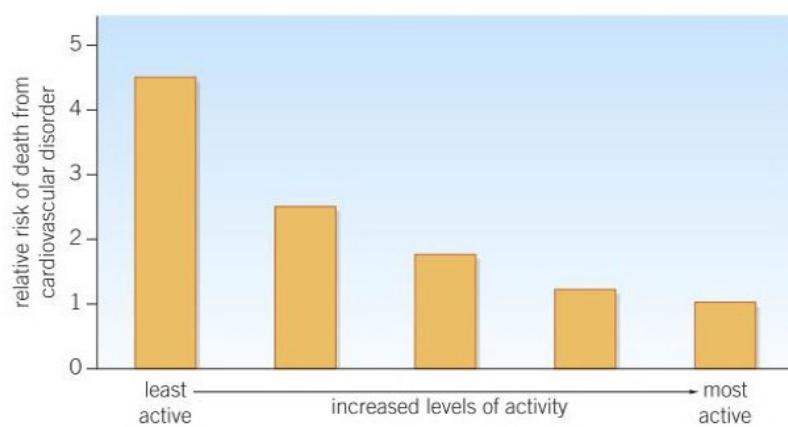
The food you eat transfers energy to your muscles as they work from respiration, so the amount of exercise you do affects the amount of respiration in your muscles, and the amount of food you need. People who exercise regularly are usually much fitter than people who take little exercise. People who take regular exercise make bigger muscles, up to 40% of their body mass, and muscle tissue needs much more energy to be transferred from food than body fat. People who exercise regularly have fitter hearts and bigger lungs than people who don't exercise. But exercise doesn't always mean time spent training or 'working out' in the gym. Walking to school, running around the house looking after small children, or doing a physically active job all count as exercise too. Between 60 and 75% of your daily food intake is needed for the basic reactions that keep you alive. About 10% is needed to digest your food so only the final 15–30% is affected by your physical activity!

Scientists and doctors have collected lots of evidence that people who exercise regularly are less likely to develop cardiovascular disease than people who do not exercise. They are less likely to suffer from many other health problems too, including type 2 diabetes (see later).

## Synoptic link



You can find out about the effect of fitness on the way the body reacts to exercise in Topic B9.2.



**Figure 1** The effect of exercise on the risk of death associated with cardiovascular disease in men and women

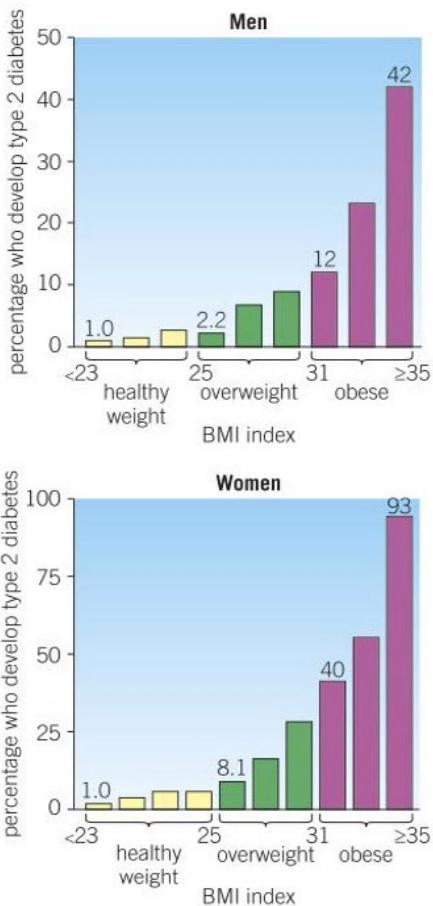
Here are some of the causal mechanisms that explain why exercise helps to keep you healthy. You will have more muscle tissue, increasing your metabolic rate, so you are less likely to be overweight. This reduces the risk of developing arthritis, diabetes, and high blood pressure, for example. Your heart will be fitter and develop a better blood supply. Regular exercise lowers your blood cholesterol levels and helps the balance of the different types of cholesterol. This reduces your risk of fatty deposits building up on your coronary arteries, so lowering your risk of heart disease and other health problems.

## Obesity and type 2 diabetes

In type 2 diabetes, either your body doesn't make enough insulin to control your blood sugar levels or your cells stop responding to insulin. This can lead to problems with circulation, kidney function, and eyesight, which may eventually lead to death. Type 2 diabetes gets more common with age and some people have a genetic tendency to develop it. The evidence is now overwhelming that being overweight or obese and not doing much exercise are risk factors for type 2 diabetes at any age. Type 2 diabetes is becoming increasingly common in young people. By 2025, an estimated 4 million people in the UK will have diabetes and 90% of those cases will be type 2. Fortunately most people can restore their normal blood glucose balance simply by eating a balanced diet with controlled amounts of carbohydrate, losing weight, and doing regular exercise.

## Synoptic links

You will learn more about both type 1 and type 2 diabetes in Topic B11.2 and Topic B11.3.



**Figure 2** The effect of obesity on the risk of developing type 2 diabetes in men and women

- 1 Explain why people who exercise regularly are usually healthier than people who take little exercise. [5 marks]
- 2 Exercise levels and obesity levels are often linked. Suggest reasons for this. [4 marks]
- 3 Based on the data in Figure 1, what is the relative risk of suffering cardiovascular disease in men who exercise least compared to men who exercise most? [2 marks]
- 4 Type 2 diabetes has been described as an epidemic. It was observed that if it is an epidemic, it is an epidemic that particularly affects women. Look at the data in Figure 2 and evaluate these statements, taking into account the scientific evidence. Suggest both the reasons for the observations and how the 'epidemic' might be controlled. [6 marks]

## Key points

- Diet affects your risk of developing cardiovascular and other diseases directly through cholesterol levels and indirectly through obesity.
- Exercise levels affect the likelihood of developing cardiovascular disease.
- Obesity is a strong risk factor for type 2 diabetes.

# B7.5 Alcohol and other carcinogens

## Learning objectives

After this topic, you should know:

- that alcohol affects liver and brain function
- that alcohol can affect unborn babies
- that alcohol is a carcinogen
- that many other agents act as carcinogens.

## Study tip

Be clear that both ionising radiation and chemicals, such as the tar in tobacco smoke and alcohol, can act as carcinogens.

## Synoptic links

You learnt about the role of the liver in Topic B3.7. You will learn more about the brain in Topic B10.4.

There are many different agents that increase your risk of developing non-communicable diseases. Some of these you may take into your body willingly, and some you may be unaware of.

## Alcohol and health

Alcohol (ethanol) is a commonly used social drug in many parts of the world. It is poisonous but the liver can usually remove it before permanent damage or death results. Alcohol is also very addictive.

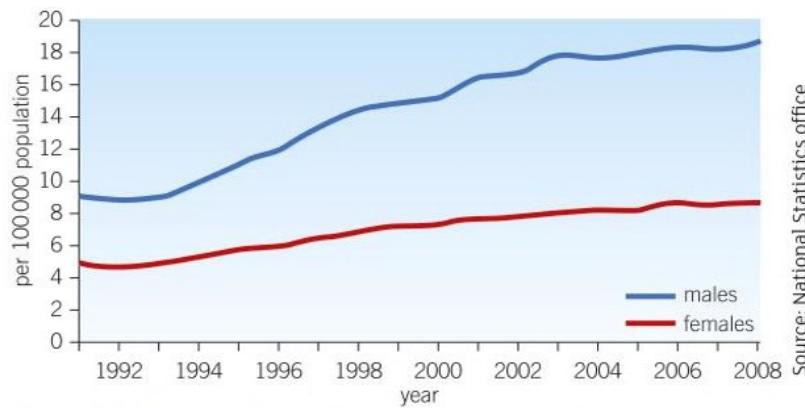
After an alcoholic drink, the ethanol is absorbed into the blood from the gut and passes easily into the body tissues, including the brain. It affects the nervous system, making thought processes, reflexes, and many reactions slower than normal. In small amounts alcohol makes people feel relaxed, cheerful, and reduces inhibitions. Larger amounts lead to lack of self-control and lack of judgement. If the dose of alcohol is too high, it can sometimes lead to unconsciousness, coma, and death.

## Brain and liver damage

People can easily become addicted to alcohol, needing the drug to function, and they may drink heavily for many years. Their liver and brain may suffer long-term damage and eventually the alcohol can kill them:

- They may develop cirrhosis of the liver, a disease that destroys the liver tissue. The active liver cells are replaced with scar tissue that cannot carry out vital functions.
- Alcohol is a carcinogen so heavy drinkers are at increased risk of developing liver cancer. This usually spreads rapidly and is difficult to treat.
- Long-term heavy alcohol use also causes damage to the brain. In some alcoholics the brain becomes so soft and pulpy that the normal brain structures are lost and it can no longer function properly. This too can cause death.

The damage to the liver and brain associated with heavy drinking usually develops over years, but short bouts of very heavy drinking risk the same symptoms appearing relatively fast, even in young people.



**Figure 1** This graph shows the increase in alcohol-related deaths in the UK between 1990 and 2008

## Alcohol and pregnancy

If a pregnant woman drinks alcohol, it passes across the placenta into the developing baby. Miscarriage, stillbirths, premature births, and low birthweight are all risks linked to drinking alcohol during pregnancy. The developing liver cannot cope with alcohol, so the development of the brain and body of an unborn baby can be badly affected, especially in the early stages of pregnancy.

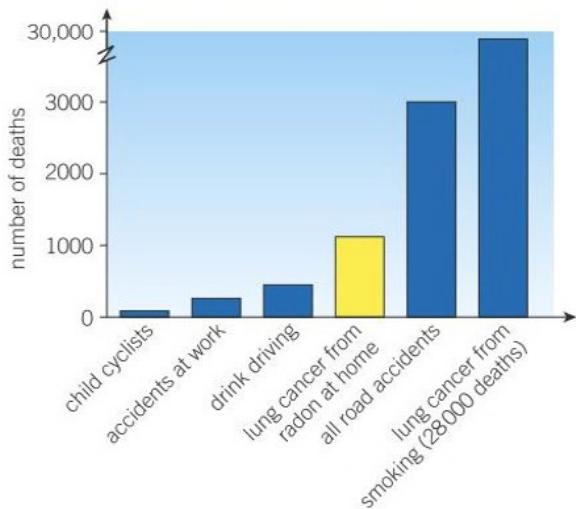
The baby may have facial deformities, problems with its teeth, jaw or hearing, kidney, liver, and heart problems, and may have learning and other developmental problems. This is known as fetal alcohol syndrome (FAS). Doctors are not sure how much alcohol is safe during pregnancy. The best advice is not to drink at all to avoid fetal alcohol syndrome. The more you drink, the higher the risk to the unborn baby.

## Ionising radiation

Ionising radiation in the form of different types of electromagnetic waves is a well-known carcinogen (risk factor for cancer). Radioactive materials are a source of ionising radiation. The radiation penetrates the cells and damages the chromosomes, causing mutations in the DNA. The more you are exposed to ionising radiation, the more likely it is that mutations will occur and that cancer will develop.

Ionising radiation is particularly dangerous when taken directly into your body. For example, breathing radioactive materials into the lungs enables the ionising radiation to penetrate directly into the cells. Well-known sources of ionising radiation include:

- Ultraviolet light from the sun – this increases the risk of skin cancers such as melanoma (protection includes sunscreen and sensible clothing).
- Radioactive materials found in the soil, water, and air (including radon gas in granite-rich areas such as Cornwall and the Pennines).
- Medical and dental X-rays.
- Accidents in nuclear power generation, especially accidents such as the one in Chernobyl, Ukraine in 1986, can spread ionising radiation over wide areas.



**Figure 2** Living in a home contaminated by radon gas can increase your risk of dying from lung cancer, especially if you are also a smoker. However, the number of people directly affected is small compared to the number who die each year as a result of smoking tobacco, or from road accidents

- 1 **a** Define a carcinogen. [1 mark]
- b** Name three different carcinogens. [3 marks]
- 2 Use data from Figure 1 to help you answer the following.
  - a** How many men and women died of alcohol-related diseases per 100 000 of the population in 1992? [2 marks]
  - b** How many men and women died of alcohol-related diseases per 100 000 of the population in 2008? [2 marks]
  - c** Suggest reasons for this increase in alcohol-related deaths. [3 marks]
  - d** Explain why you think alcohol remains a legal drug when it causes so many deaths. [3 marks]

## Key points

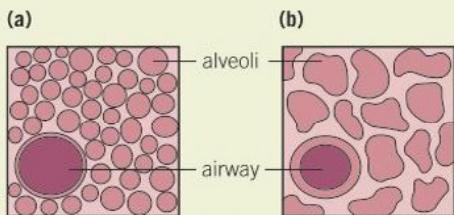
- Alcohol can damage the liver and cause cirrhosis and liver cancer.
- Alcohol can cause brain damage and death.
- Alcohol taken in by a pregnant woman can affect the development of her unborn baby.

# B7 Non-communicable diseases

## Summary questions

- 1 a What is a non-communicable disease? [1 mark]
- b Define a lifestyle factor and give three examples. [3 marks]
- c Explain what is meant by:
- i a correlation between a lifestyle factor and a non-communicable disease [2 marks]
  - ii a causal link between a lifestyle factor and a particular disease. [3 marks]

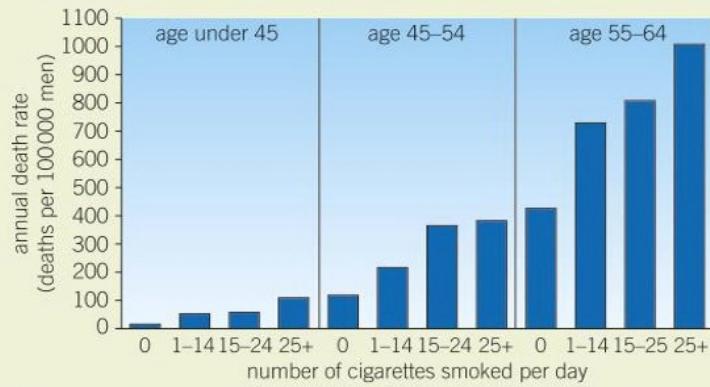
2



**Figure 1** This diagram shows areas of lung tissue from two people. One is a non-smoker a, the other is a long-term smoker who has developed COPD, b

- a Which sample of tissue is from the non-smoker? Explain your choice. [3 marks]
- b What are the main symptoms of COPD? [2 marks]
- c Explain how smoking causes COPD and the reason for the symptoms. [5 marks]
- d The risk of having a number of diseases (like COPD) increases with the number of cigarettes smoked a day and the length of time someone has been a smoker.
- i Name two more of these smoking-related diseases. [2 marks]
  - ii Explain how both the number of cigarettes smoked and the time someone has been a smoker affects their risk of developing a smoking-related disease. [4 marks]

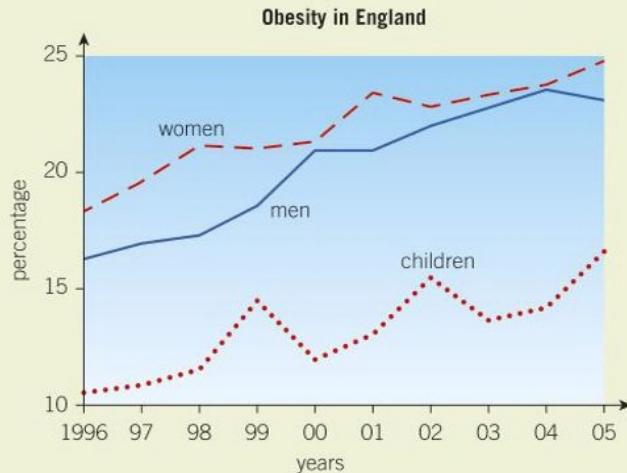
- 3 The following chart shows the effect of smoking on the annual death rate in men.



**Figure 2** Effect of smoking on the annual death rate for men

- a i What is the annual death rate per 100 000 men aged 55–64 who smoke 1–14 cigarettes a day? [1 mark]
- ii The death rate of men aged 45–54 who smoke more than 25 cigarettes a day is higher than the death rate for non-smokers. How much higher is it per 100 000 men? [3 marks]
- b Explain why the death rate for smokers is higher than the death rate for non-smokers in each age group. [3 marks]
- 4 a Which two body organs are most affected by a large amount of alcohol over a long period of time? [2 marks]
- b Explain why it is unsafe for someone to drive when they have been drinking alcohol. [4 marks]
- c Alcohol is closely linked to violence and crime. Suggest why alcohol has this effect. [3 marks]
- d Pregnant women are advised not to drink alcohol, even though scientists do not have clear evidence of exactly what level of alcohol consumption is safe for the unborn baby. Explain why this is sensible advice.  [6 marks]

- 5 a Look at Figure 3. Describe the trend in obesity in England between 1996 and 2005. [1 mark]
- b Suggest reasons for the observed trend in obesity. [4 marks]
- c A similar graph shows a rise in type 2 diabetes over the same time scale. Suggest how the two sets of data may be linked. [4 marks]



**Figure 3** Trends in obesity in England between 1996 and 2005

## Practice questions

- 01** Non-communicable diseases can be linked to a range of risk factors. Match each disease to its main risk factor.

Disease	Main risk factor
liver disease	alcohol
skin cancer	ionising radiation
type 2 diabetes	obesity smoking

[3 marks]

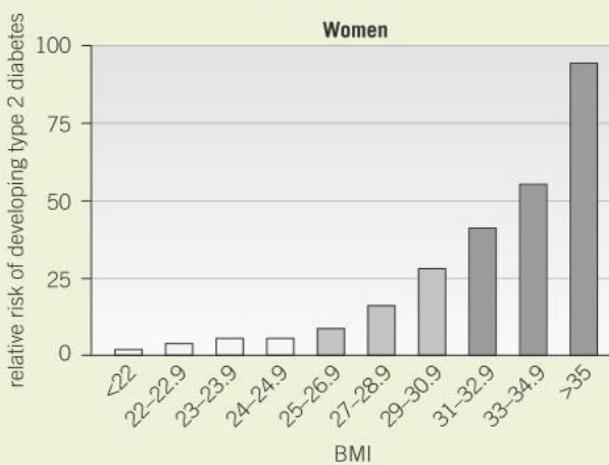
- 02** Body mass index (BMI) is a measure of whether a person is a healthy mass for their height.  
BMI is calculated using the equation:

$$\text{BMI} = \frac{\text{body mass in kg}}{(\text{height in m})^2}$$

- 02.1** A woman has a mass of 92 kg and a height of 1.7 m. Use the equation to calculate her BMI. [2 marks]

**Figure 1** shows the relative risk of developing Type 2 diabetes in women for different BMI values.

**Figure 1**



- 02.2** Use your answer from **02.1** to determine the relative risk for this woman of developing type 2 diabetes. [1 mark]

- 02.3** Describe the trend shown in **Figure 1**. [2 marks]

- 02.4** Suggest **one** other factor that can affect a person's risk of developing Type 2 diabetes. [1 mark]

- 02.5** A man went to a doctor with symptoms that could indicate diabetes.

What blood test would confirm that the man had diabetes? [1 mark]

- 02.6** If it was confirmed the man had diabetes the doctor would recommend some changes the man could make to his lifestyle.

Suggest **two** changes the man could make to help control his diabetes. [2 marks]

- 03** Cancers are the result of uncontrolled cell growth and division.

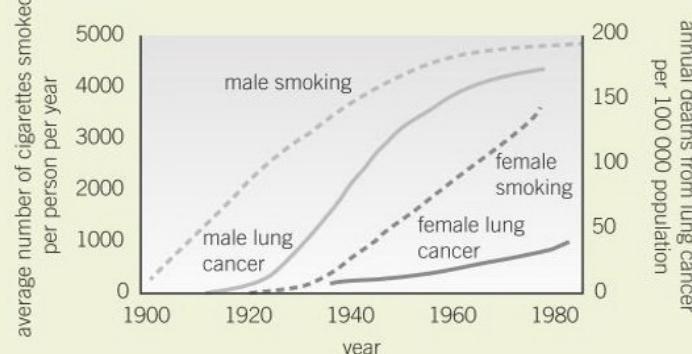
- 03.1** What type of cell division occurs in cancer cells? [1 mark]

- 03.2** Describe how a cancer can spread to different parts of the body. [2 marks]

**Figure 2** shows the number of deaths from lung cancer and the average number of cigarettes smoked for men and women.

- 03.3** Give **three** conclusions that can be made from **Figure 2**. [3 marks]

**Figure 2**



- 03.4** Give **one** other non-communicable disease associated with smoking cigarettes. [1 mark]

- 04** Health is a state of physical and mental well-being. Describe some things a person could do **and** things they could avoid, in order to stay healthy. Explain how these actions would help the person to stay healthy. [6 marks]

# B 8 Photosynthesis

## 8.1 Photosynthesis

### Learning objectives

After this topic, you should know:

- the raw materials and energy source for photosynthesis
- that photosynthesis is an endothermic reaction
- the equations that summarise photosynthesis.

### Study tip

Learn the equation for photosynthesis.

Remember that photosynthesis is endothermic – energy is transferred from the environment to the chloroplast by light.

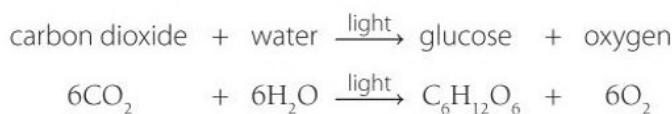
All organisms, including plants and algae, need food for respiration, growth, and reproduction. However, plants don't need to eat – they can make their own food by **photosynthesis**. This takes place in the green parts of plants (especially the leaves) when it is light. Algae can also carry out photosynthesis.

### The process of photosynthesis

The cells in algae and plant leaves are full of small green parts called chloroplasts, which contain a green substance called chlorophyll. During photosynthesis, energy is transferred from the environment to the chloroplasts by light. This energy is then transferred to convert carbon dioxide ( $\text{CO}_2$ ) from the air, plus water ( $\text{H}_2\text{O}$ ) from the soil into a simple sugar called **glucose** ( $\text{C}_6\text{H}_{12}\text{O}_6$ ). The chemical reaction also produces oxygen gas ( $\text{O}_2$ ) as a by-product. The oxygen is released into the air, which you can then use when you breathe it in. Every year plants produce about 368 000 000 000 tonnes of oxygen, so there is plenty to go around.

Photosynthesis is an **endothermic reaction** – it needs an input of energy from the environment. The energy transferred from the environment when the bonds holding carbon dioxide and water are broken is more than that transferred back to the environment with the formation of the new bonds in glucose and oxygen. The extra energy required for the reaction to take place is transferred from the environment by light.

Photosynthesis can be summarised as follows:



Some of the glucose produced during photosynthesis is used immediately by the cells of the plant for respiration. However, a lot of the glucose is converted into insoluble starch and stored.



### Producing oxygen

You can show that a plant is photosynthesising by the oxygen gas it gives off as a by-product. Oxygen is a colourless gas, so in land plants it isn't easy to show that it is being produced. However, if you use water plants such as *Cabomba* or *Elodea*, you can see and collect the bubbles of gas they give off when they are photosynthesising. The gas will relight a glowing splint, showing that it is rich in oxygen.



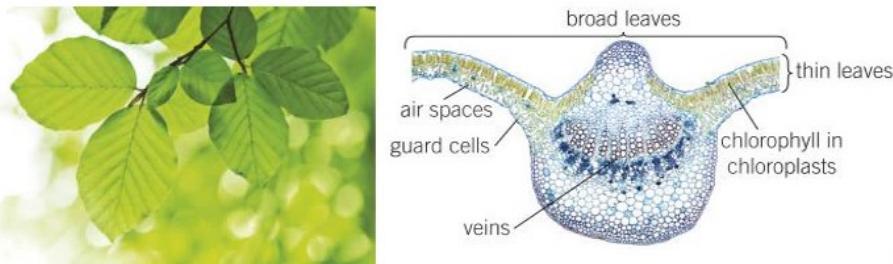
**Figure 1** The oxygen produced during photosynthesis is vital for life on Earth. You can demonstrate that it is produced using water plants such as this *Cabomba*.

## Leaf adaptations

For photosynthesis to be successful, a plant needs plenty of carbon dioxide, light, and water. The leaves of plants are perfectly adapted as organs of photosynthesis because:

- most leaves are broad, giving them a big surface area for light to fall on
- most leaves are thin so diffusion distances for the gases are short
- they contain chlorophyll in the chloroplasts to absorb light
- they have veins, which bring plenty of water in the xylem to the cells of the leaves and remove the products of photosynthesis in the phloem
- they have air spaces that allow carbon dioxide to get to the cells, and oxygen to leave by diffusion
- they have guard cells that open and close the stomata to regulate gas exchange.

These adaptations mean that the plant can photosynthesise as much as possible whenever there is light available.



**Figure 2** Leaves are well-adapted for photosynthesis

Algae are aquatic so they are adapted to photosynthesising in water. They have a large surface area and absorb carbon dioxide dissolved in the water around them. The oxygen they produce also dissolves in the water around them as it is released.

- 1 **a** Describe where a plant gets the carbon dioxide and water that it needs for photosynthesis. [2 marks]
- b** Describe where algae get the carbon dioxide, water, and light they need for photosynthesis. [3 marks]
- 2 Describe the path taken by a carbon atom as it moves from being part of the carbon dioxide in the air to being part of a starch molecule in a plant. [5 marks]
- 3 Explain why a leaf kept in the light for 24 hours will turn an iodine solution blue-black, whereas a leaf kept in the light for 24 hours and then in the dark for 24 hours will have no effect on an iodine solution. [4 marks]
- 4 **a** Give the word equation for photosynthesis. [2 marks]
- b** Explain why photosynthesis is an endothermic reaction. [3 marks]

## Synoptic links

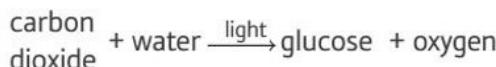
For more information on the structure and function of plant cells, see Topic B1.5.

## Go further

Scientists are working hard to make sure crop plants carry out as much photosynthesis as possible. They are trying to increase the amount of chlorophyll in some plants, and make photosynthesis more efficient in others. These changes could help us grow more food. If they also remove more carbon dioxide from the atmosphere it might help reduce global warming.

## Key points

- Photosynthesis is an endothermic reaction.
- During photosynthesis energy is transferred from the environment to the chloroplast by light. It is used to convert carbon dioxide and water into sugar (glucose). Oxygen is also formed and released as a by-product.
- Photosynthesis can be shown as follows:



- Leaves are well adapted to allow the maximum amount of photosynthesis to take place.

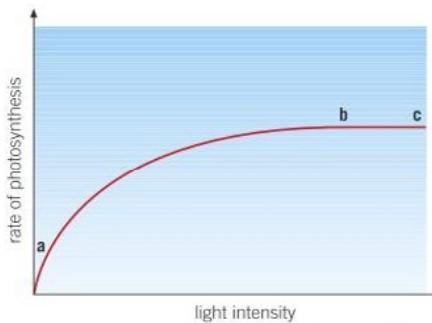


# B8.2 The rate of photosynthesis

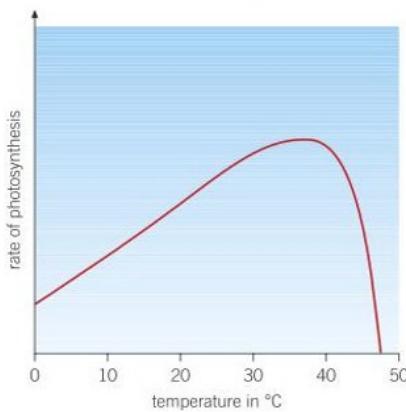
## Learning objectives

After this topic, you should know:

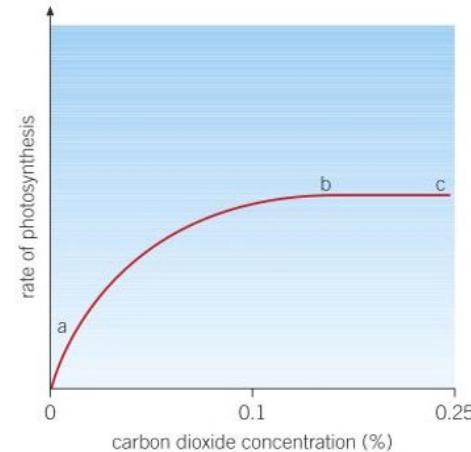
- which factors limit the rate of photosynthesis in plants.



**Figure 1** Investigating the effect of light intensity on the rate of photosynthesis



**Figure 2** The effect of increasing temperature on the rate of photosynthesis



**Figure 3** The effect of increasing carbon dioxide concentration on the rate of photosynthesis

You may have noticed that plants grow quickly in the summer, yet they hardly grow at all in the winter. Plants need light, warmth, and carbon dioxide if they are going to photosynthesise and grow as fast as they can. Sometimes any one or more of these things can be in short supply and limit the amount of photosynthesis a plant can manage. This is why they are known as **limiting factors**.

## Light

The most obvious factor affecting the rate of photosynthesis is light intensity. If there is plenty of light, lots of photosynthesis can take place. If there is very little or no light, photosynthesis will stop, whatever the other conditions are around the plant. For most plants, the brighter the light, the faster the rate of photosynthesis (Figure 1).

## Temperature

Temperature affects all chemical reactions, including photosynthesis. As the temperature rises, the rate of photosynthesis increases as the reaction speeds up. However, photosynthesis is controlled by enzymes. Most enzymes are denatured once the temperature rises to around 40–50 °C. If the temperature gets too high, the enzymes controlling photosynthesis are denatured and the rate of photosynthesis will fall (Figure 2).

## Carbon dioxide concentration

Plants need carbon dioxide to make glucose. The atmosphere is only about 0.04% carbon dioxide. This means carbon dioxide often limits the rate of photosynthesis. Increasing the carbon dioxide concentration will increase the rate of photosynthesis (Figure 4).

On a sunny day, carbon dioxide concentration is the most common limiting factor for plants. The carbon dioxide concentrations around a plant tend to rise at night, because in the dark a plant respires but doesn't photosynthesise. As light intensity and temperature increase in the morning, most of the carbon dioxide around the plant gets used up.

In a science lab or a greenhouse the levels of carbon dioxide can be increased artificially. This means that carbon dioxide is no longer the limiting factor. Then the rate of photosynthesis increases with the rise in carbon dioxide concentration.

In a garden, woodland or field (rather than a lab or greenhouse, where conditions can be controlled), light intensity, temperature, and carbon dioxide concentrations interact, and any one of them might be the factor that limits photosynthesis.



## Light intensity and rate of photosynthesis

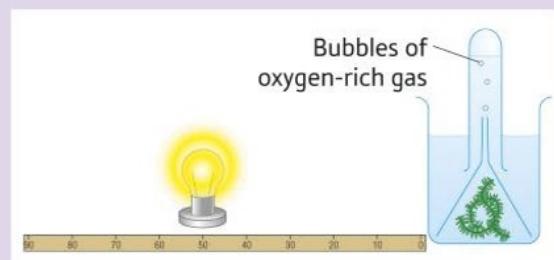
You can investigate the effect of light intensity on the rate of photosynthesis (Figure 4).

At the beginning of the investigation, the rate of photosynthesis in the water plant increases as the light is moved closer to the plant, which increases the light intensity. This tells us that light is acting as a limiting factor. When the light is moved further away from the water plant, the rate of photosynthesis falls, shown by a slowing down in the stream of bubbles produced. If the light is moved closer again the stream of bubbles becomes faster, showing an increased rate of photosynthesis. We often add a heat shield to the apparatus in Figure 4. This helps keep the temperature of the water around the plant constant regardless of the position of the light source.

Eventually, no matter how close the light, the rate of photosynthesis stays the same. At this point, light is no longer limiting the rate of photosynthesis. Something else has become the limiting factor.

The results can be plotted on a graph showing the effect of light intensity on the rate of photosynthesis (Figure 1).

**Safety:** keep electrical equipment dry and do not handle if hands are wet.



**Figure 4** Simple apparatus for investigating the effect of light intensity on the rate of photosynthesis

Higher

## Light intensity and the inverse square law

The relationship between light intensity and the rate of photosynthesis is not a simple one. This is because light intensity involves the inverse square law.

As the distance of the light from the plant increases, the light intensity decreases. That is an inverse relationship – as one goes up the other goes down. However the relationship between distance and light intensity is not linear. The light intensity decreases or increases in inverse proportion to the square of the distance.

$$\text{Light intensity} \propto \frac{1}{\text{distance}^2}$$

For example, if you double the distance between the light and your plant, light intensity falls by a quarter.

$$\text{Light intensity} \propto \frac{1}{2^2} = \frac{1}{4}$$

## Chlorophyll levels in the leaf

If the amount of chlorophyll in a leaf is limited in any way, less photosynthesis will take place. The leaves of some ornamental plants have white, chlorophyll-free areas. These plants grow less vigorously than plants with all green leaves. If they are permanently in dim light, variegated leaves often turn completely green. If a plant does not have enough minerals, especially magnesium, it cannot make chlorophyll. The rate of photosynthesis drops and eventually the plant may die.

- 1 Name the three main limiting factors that affect the rate of photosynthesis in a plant. [3 marks]
- 2 Look at the graph in Figure 1.
  - a Explain what is happening between points **a** and **b** on the graph. [2 marks]
  - b Explain what is happening between points **b** and **c** on the graph. [2 marks]
  - c Now look at Figure 2. Explain why it is a different shape to the graphs in Figures 1 and 3. [4 marks]
- 3 Explain in terms of limiting factors why the plants growing in a tropical rainforest are so much bigger than the plants that grow in a UK woodland, and why both are bigger than the plants on the Arctic tundra. [6 marks]

## Key points

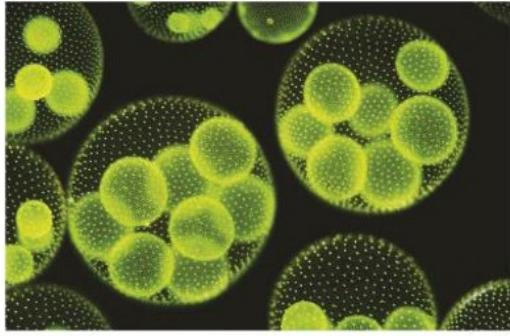
- The rate of photosynthesis may be affected by light intensity, temperature, level of carbon dioxide, and the amount of chlorophyll.

# B8.3 How plants use glucose

## Learning objectives

After this topic, you should know:

- how plants use the glucose they make
- the extra materials that plant cells need to produce proteins
- some practical tests for starch, sugars, and proteins.



**Figure 1** Worldwide, photosynthesis in algae like this Volvox produces more oxygen and biomass than photosynthesis in plants, but they are often forgotten about

## Synoptic links

For more information on the cellulose wall in plant cells, see Topic B1.2, and Topic B1.7.

To find out more about respiration in cells, see Topic B9.1.



## Synoptic links

For more information on transport in plants, see Topic B4.7.

For more on osmosis in plants, see Topic B1.7.



Plants make food by photosynthesis in their leaves and other green parts. Algae also photosynthesise. So how do they use the glucose they make?

## Using glucose

Plant cells and algal cells, like any other living cells, respire all the time. They use some of the glucose produced during photosynthesis as they respire. The glucose is broken down using oxygen to provide energy for the cells. Carbon dioxide and water are the waste products of the reaction. Chemically, respiration is the reverse of photosynthesis.

## Cellulose for strength, starch for storage

Energy transferred in respiration may be used to build smaller molecules into bigger molecules. For example, plants build up glucose into complex carbohydrates such as cellulose. They use this to strengthen their cell walls.

Plants convert some of the glucose produced in photosynthesis into starch to be stored. Glucose is soluble in water. If it were stored in plant cells, it could affect the way water moves into and out of the cells by osmosis. Lots of glucose stored in plant cells could affect the water balance of the whole plant.

Starch is insoluble in water. It has no effect on the water balance of the plant so plants can store large amounts of starch in their cells. Starch is the main energy store in plants and it is found in cells all over a plant:

- Starch is stored in the cells of the leaves. It provides an energy store for when it is dark or when light levels are low.
- Starch is also kept in special storage areas of a plant. For example, many plants produce tubers and bulbs that are full of stored starch, to help them survive through the winter. Humans often take advantage of these starch stores, found as vegetables such as potatoes and onions.



## Testing for starch

The presence of starch in a leaf is evidence that photosynthesis has taken place. You can test for starch using the iodine solution test and also use this test to show that light is vital for photosynthesis to take place.

Take a leaf from a plant kept in the light and a plant kept in the dark for at least 24 hours. Just adding iodine solution to a leaf does not work, because the waterproof cuticle keeps the iodine out. Leaves have to be specially prepared so the iodine solution can reach the cells and react with any starch stored there. Also, the green chlorophyll would mask any colour changes if the iodine did react with the starch. You therefore need to treat the leaves by boiling them in ethanol, to destroy the waxy cuticle and then to remove the colour. The leaves are then rinsed in hot water to soften them. After treating the leaves, add iodine solution to them both. Iodine solution turns blue-black in the presence of starch.

The leaf that has been in the light will turn blue-black. The iodine solution on the leaf kept in the dark remains orange-red (Figure 2).

**Safety:** Take care when using ethanol. It is volatile, highly flammable, and harmful. Always wear eye protection. No naked flames – use a hot water bath to heat ethanol.



**Figure 2** The results of the iodine test for starch on a leaf kept in the light (on the left) and a leaf kept in the dark (on the right).

## Nitrates, proteins and carnivorous plants

Plants use some of the glucose from photosynthesis to make amino acids. They do this by combining sugars with nitrate ions and other mineral ions from the soil. These amino acids are then built up into proteins to be used in the plant cells in many ways, including as enzymes. This uses energy from respiration.

Algae also make amino acids. They do this by taking the nitrate ions and other materials they need from the water they live in.

Very few plants can survive well if the soil they are growing in is low in minerals. For example, bogs are wet and their peaty soil has very few nutrients in it. This makes it a difficult place for plants to live.

Some carnivorous plants, such as pitcher plants, Venus flytraps, and sundews are especially adapted to live in nitrate-poor soil. They can survive because they obtain most of their nutrients from the animals, such as insects, that they catch. The plants produce enzymes to digest the insects they trap. They then use nitrates and other minerals from the digested bodies of their victims in place of the nutrients they cannot get from the bog soil in which they grow. After an insect has been digested, the trap reopens, ready to try again.

## Making lipids

Plants and algae use some of the glucose from photosynthesis and energy transferred from respiration to build up fats and oils. These may be used in the cells as an energy store. They are sometimes used in the cell walls to make them stronger. In addition, plants often use fats or oils as an energy store in their seeds. Seeds provide food for the new plant to respire as it germinates. Some algal cells are also very rich in oils. They are even being considered as a possible source of biofuels for the future.

- 1 Name three ways that a plant uses the glucose produced by photosynthesis. [3 marks]
- 2 **a** Describe where you might find starch in a plant. [4 marks]
  - b** Explain why some of the glucose made by photosynthesis is converted to starch. [3 marks]
  - c** Suggest how you could demonstrate that a potato is a store of starch. [3 marks]
- 3 Look at Figure 2. Explain fully why the two leaves look so different. [4 marks]
- 4 Explain why pitcher plants, sundews, and Venus fly traps are often found growing in bogs globally, an environment where not many other plants can survive. [6 marks]

### Study tip

Two important points to remember:

- Plants **respire** 24 hours a day to transfer useable energy for the cells.
- Glucose is soluble in water, but starch is insoluble.

### Synoptic link

You can remind yourself of the Biuret test for proteins in Topic B3.3.



**Figure 3** Sundews trap insects on their sticky hairs and digest them where they are stuck to make use of the valuable nitrates and other minerals

### Key points

- Plant and algal cells use the glucose produced during photosynthesis for respiration, to convert into insoluble starch for storage, to produce fats or oils for storage, to produce cellulose to strengthen cell walls, and to produce amino acids for protein synthesis.
- Plants and algal cells also need nitrate ions absorbed from the soil or water to make the amino acids used to make proteins.

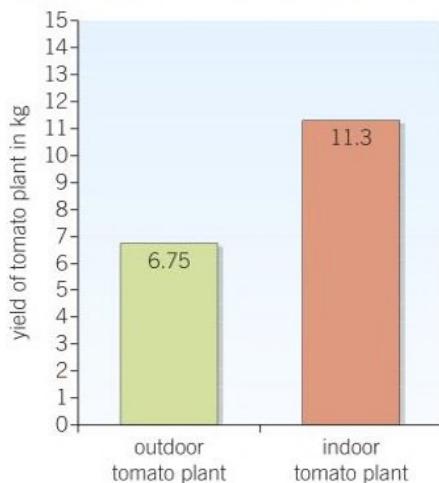


# B8.4 Making the most of photosynthesis

## Learning objectives

After this topic, you should know:

- how the different factors affecting the rate of photosynthesis interact
- how humans can manipulate the environment in which plants grow.



**Figure 1** One piece of American research showed the crop yield for tomatoes was almost doubled in a greenhouse

The more a plant photosynthesises, the more biomass it makes and the faster it grows. It's not surprising that farmers want their plants to grow as fast and as big as possible. It makes more food for people to eat and helps them to make a profit.

In theory, if you give plants a warm environment with plenty of light and carbon dioxide, and water, they should grow as fast as possible. Out in the fields it is almost impossible to manipulate any of these factors. However, people have found a number of ways that they can artificially manipulate the environment of their plants – and get a number of benefits from doing so.

## The garden greenhouse

Lots of people have a greenhouse in their garden. The first recorded greenhouse was built in about AD 30 for Tiberius Caesar, a Roman emperor who wanted to eat cucumbers out of season. Glass hadn't been invented so they used sheets of the mineral mica to build it. Now farmers use huge plastic 'polytunnels' as giant greenhouses for growing crops from tomatoes to strawberries and potatoes.

How does a greenhouse affect the rate of photosynthesis? The glass or plastic building means that the environment is much more controllable than in an ordinary garden or field. Most importantly, the atmosphere is warmer inside than out. This affects the rate of photosynthesis, speeding it up so plants grow faster, flower and fruit earlier, and crop better. In the UK, greenhouses can be used to grow fruit like peaches, lemons, and oranges which don't grow well outside.

## Controlling everything

More and more farmers are taking the idea of the greenhouse a bit further. In the laboratory you can isolate different factors and see how they limit the rate of photosynthesis. However, for most plants it is usually a mixture of these factors that affects them. Early in the morning, light levels and temperature probably limit the rate of photosynthesis. Then as the levels of light and temperature rise, carbon dioxide levels become limiting. On a bright, cold winter day, temperature probably limits the rate of the process. There is a constant interaction between the different factors. Remind yourself of the effects of limiting factors on the rates of photosynthesis in Topic B8.2.

Big commercial greenhouses now take advantage of what is known about limiting factors. They control not only the temperature but also the levels of light and carbon dioxide to get the fastest possible rates of photosynthesis. As a result the plants grow as quickly as possible. The plants are even grown in water with a perfect balance of nutrients instead of soil to make sure nothing slows down their growth. This type of system is known as hydroponics.

These greenhouses are enormous and conditions are controlled using computer software. It costs a lot of money but manipulating the environment has many benefits. You can change the carbon dioxide levels in the greenhouses during the day as well as the temperature and the light levels. Furthermore, you can change the mineral content of the water as the plants get bigger.

Turnover is fast which means profits can be high. The crops are clean and soil-free. There is no need to plough or prepare the land in these systems, and crops can be grown where the land is poor.

## Greenhouse economics

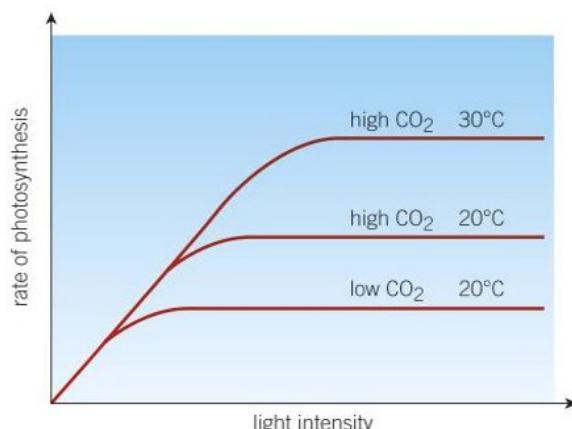
It takes a lot of planning to keep conditions in the greenhouses just right. Electricity and gas are used to maintain the lighting and temperatures and to control the carbon dioxide levels. Expensive monitoring equipment and computers are needed to maintain conditions inside the greenhouse within narrow boundaries, and alarms are vital if things go wrong. On the other hand, less staff are needed, the time from seed to harvest is much shorter, and the final crop is larger and cleaner. All of these factors, along with the size of the business, have to be considered when deciding whether an enclosed system will increase or reduce profits. The increased income from a larger crop and the ability to grow more crops each year has to be balanced against the cost of setting up and maintaining the system.

There are many decisions for growers to make, but for plants grown hydroponically, limiting factors are a thing of the past.

- 1 a** Explain the main differences between a garden greenhouse and a hydroponics growing system. [3 marks]
- b** Explain the main benefits of artificially manipulating the environment in which food plants are grown. [3 marks]
  
- 2 a** In each of these situations, identify the one factor that is most likely to be limiting photosynthesis. In each case explain why the rate of photosynthesis is limited.
  - i** A wheat field first thing in the morning [3 marks]
  - ii** The same field later on in the day [3 marks]
  - iii** Plants growing on a woodland floor in winter [3 marks]
  - iv** Plants growing on a woodland floor in summer. [3 marks]
- b** Explain why it is impossible to be certain which factor is involved in each of these cases. [3 marks]
  
- 3** Use Figure 3 to answer this question.  
The cost of running a large greenhouse is particularly affected by the levels of light and temperature. If plants are provided with plenty of carbon dioxide the grower can get two crops a year at 20°C and three crops a year at 30°C. Explain why many growers use 20°C rather than 30°C in their greenhouses. In your explanation suggest why many growers are also investing in insulation systems that can be added and removed electronically. [6 marks]



**Figure 2** By controlling the temperature, light, and carbon dioxide levels in a greenhouse like this you can produce the biggest possible crops.



**Figure 3** Growers need to look at this type of data to help them decide the best economic condition for growing their plants. The cost of providing the conditions that give the very highest yields may be too expensive and may wipe out the profits from the bigger, cleaner crop

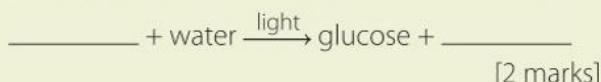
## Key points

- The factors that limit the rate of photosynthesis interact and any one of them may limit photosynthesis.
- Limiting factors are important in the economics of enhancing the conditions in greenhouses to gain the maximum rate of photosynthesis, while still maintaining profit.

# B8 Photosynthesis

## Summary questions

- 1 a Complete the word equation for photosynthesis.



- b Geraniums are green plants that grow in gardens.

- i Where does the light for photosynthesis in the geranium come from? [1 mark]
- ii How does the geranium absorb this light? [2 marks]

- c On a cold morning, the rate of photosynthesis in the geranium plant is very slow. Suggest which factors may be limiting and why. [2 marks]

- d Some of the glucose produced by the geranium plant is used for respiration. Give three other ways in which the plant uses the glucose produced in photosynthesis. [3 marks]

- e Plants grown in pure water will die, even if they are supplied with light, carbon dioxide, and a growing temperature of around 20°C. Explain why this happens. [4 marks]

- 2 The figures in Table 1 show the mean growth of two sets of oak seedlings. One set was grown in 85% full sunlight and the other set in only 35% full sunlight.

Table 1

Year	Mean height of seedlings grown in 85% full sunlight in cm	Mean height of seedlings grown in 35% full sunlight in cm
2000	12	10
2001	16	12.5
2002	18	14
2003	21	17
2004	28	20
2005	35	21
2006	36	23

- a Plot a graph to show the growth of both sets of oak seedlings. [4 marks]
- b Using what you know about photosynthesis and limiting factors, explain the difference in the growth of the two sets of seedlings. [4 marks]

- 3 Plants make food in one organ and take up water from the soil in another organ. But both the food and the water are needed all over the plant.

- a Where do plants make their food? [2 marks]
- b Where do plants take in water? [1 mark]
- c Describe how you would demonstrate that photosynthesis had taken place in the leaves of a plant. [6 marks]

- 4 Palm oil is made from the fruit of oil palms. Large areas of tropical rainforests have been destroyed to make space to plant these oil palms, which grow rapidly.

- a Explain why you think that oil palms can grow rapidly in the conditions that support a tropical rainforest. [3 marks]
- b Where does the oil in the oil palm fruit come from? [1 mark]
- c What is it used for in the plant? [2 marks]
- d How else is glucose used in the plant? [3 marks]

- 5 Table 2 shows the yields of some different plants

H grown in Bengal. The yields per acre when grown normally in the field and when grown hydroponically are compared.

Table 2

Name of crop	Hydroponic crop per acre in kg	Ordinary soil crop per acre in kg
wheat	3629	2540
rice	5443	408
potatoes	70760	8164
cabbage	8164	5896
peas	63503	11340
tomatoes	181437	9072
lettuce	9525	4080
cucumber	12700	3175

- a Explain why yields are always higher when the crops are grown hydroponically. [2 marks]

- b Which crops would be most economically sensible to grow hydroponically? Explain your choice. [4 marks]

- c Which crops would it be least sensible to grow hydroponically? Explain your choice. [3 marks]

- d Explain the benefits and problems of growing crops in:

- i the natural environment [3 marks]
- ii an artificially manipulated environment. [3 marks]

## Practice questions

**01.1** What is the correct word equation for photosynthesis?

- A carbon dioxide + glucose → oxygen + water
- B light + carbon dioxide → glucose + oxygen
- C water + carbon dioxide → glucose + oxygen
- D water + oxygen → carbon dioxide + glucose

[1 mark]

**01.2** Write down the chemical symbol for glucose.

[1 mark]

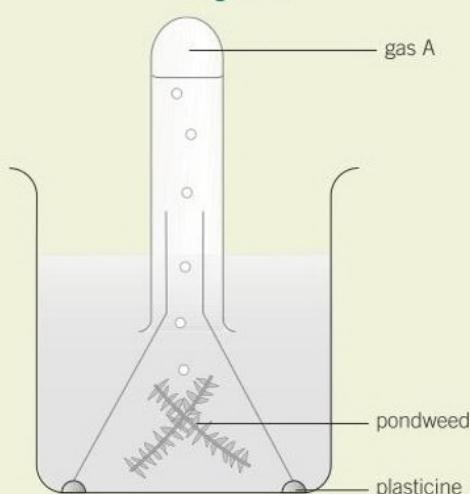
**01.3** Photosynthesis is an endothermic reaction.

What does this statement mean? [2 marks]

**01.4** Give **two** reasons why photosynthesis in plants is essential for the survival of animals. [2 marks]

**02** **Figure 1** shows the apparatus used to measure the rate of photosynthesis.

**Figure 1**



**02.1** Name gas A? [1 mark]

**02.2** Suggest why the funnel is supported on pieces of plasticine. [2 marks]

**02.3** Describe how the apparatus is used to measure the rate of photosynthesis. [2 marks]

**02.4** Give **three** factors that could affect the rate of photosynthesis in the pondweed. [3 marks]

**03** Read the following method used to test a leaf for the presence of starch.

**Step 1** Put the leaf in boiling water for 1 minute.

**Step 2** Transfer the leaf into boiling ethanol for 5 minutes.

**Step 3** Wash the leaf in hot water.

**Step 4** Spread the leaf on a white tile and cover it with iodine solution.

**03.1** Explain the purpose of each step in the method. [4 marks]

**03.2** Describe **two** safety precautions you should take in **Step 2**. [2 marks]

**Figure 2** shows a leaf that is part green and part white. It has been removed from a plant that has been in bright light.

**Figure 2**



**03.3** The leaf is tested for the presence of starch. The green part of the leaf is stained black. The white part of the leaf is stained orange. What conclusion could you make from this result? [2 marks]

**04** Plants need to make starch. Starch is used as a food storage product. Describe how plants make starch from simple raw materials. [6 marks]

# B 9 Respiration

## 9.1 Aerobic respiration

### Learning objectives

After this topic, you should know:

- the chemistry of aerobic respiration
- why cellular respiration is so important.

### Investigating respiration

Animals, plants, and microorganisms all respire. It is possible to show that cellular respiration is taking place. You can either deprive a living organism of the things it needs to respire, or show that waste products are produced from the reaction.

Depriving a living thing of food and/or oxygen would kill it. So you should concentrate on the products of respiration. Carbon dioxide is the easiest product to identify. You can also measure the energy transferred to the surroundings.

Limewater goes cloudy when carbon dioxide bubbles through it. The higher the concentration of carbon dioxide, the quicker the limewater goes cloudy. This gives us an easy way of showing that carbon dioxide has been produced. You can also look for a rise in temperature to show that energy is being transferred to the environment during respiration.

- Plan an ethical investigation into aerobic respiration in living organisms.

### Study tip

Make sure you know the word equation for aerobic respiration.

Remember that aerobic respiration takes place in the mitochondria.

One of the most important enzyme-controlled processes in living things is aerobic respiration. It takes place all the time in plant and animal cells.

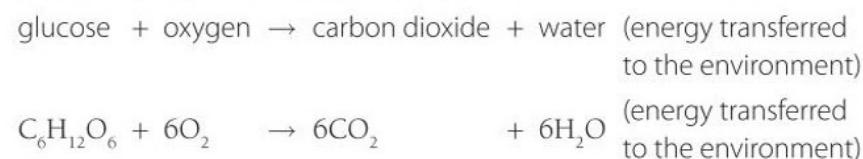
Your digestive system, lungs, and circulation all work to provide your cells with the glucose and oxygen they need for respiration.

During **aerobic respiration**, glucose (a sugar) reacts with oxygen. This reaction transfers energy that your cells can use. This energy is vital for everything that goes on in your body.

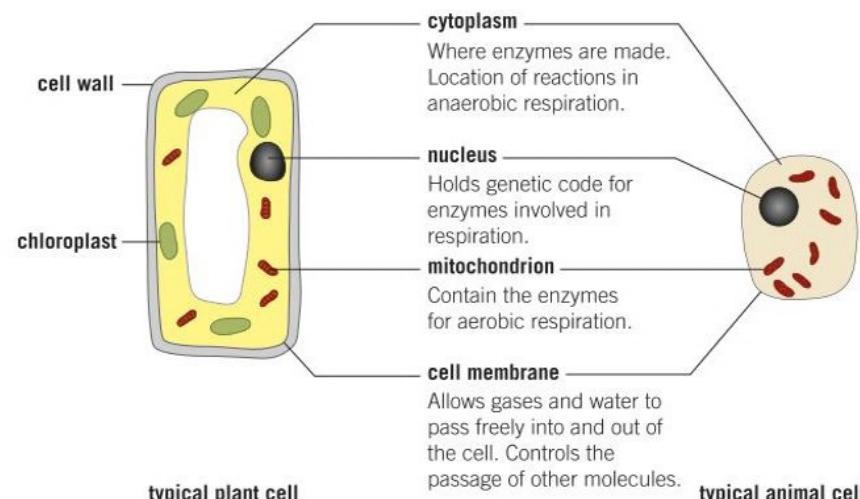
Carbon dioxide and water are produced as waste products of the reaction. The process is called aerobic respiration because it uses oxygen from the air.

Aerobic respiration is an **exothermic reaction**. Exothermic reactions transfer energy to the environment – more energy is transferred to the environment when new bonds are formed in the products than is taken in to break the bonds in the reactants. Some of the energy transferred in respiration is used for all of the reactions that take place inside a cell. The rest of the energy is transferred to the environment, making it slightly warmer.

Aerobic respiration can be summarised:



The average energy needs of a teenage boy are around 11 510 kJ daily, but teenage girls only need 8830 kJ a day. This is partly because, on average, girls are smaller than boys, and also because boys have more muscle cells. More muscle cells mean more mitochondria requiring fuel for aerobic respiration.



**Figure 1** Aerobic respiration takes place in the mitochondria, but other parts of the cell play vital roles

## Mitochondria – the site of respiration

Aerobic respiration involves lots of chemical reactions. Each reaction is controlled by a different enzyme. Most of these reactions take place in the mitochondria of your cells.

Mitochondria are tiny rod-shaped parts (organelles) that are found in almost all plant and animal cells as well as in fungal and algal cells. They have a folded inner membrane that provides a large surface area for the enzymes involved in aerobic respiration. The number of mitochondria in a cell shows you how active the cell is.

## The need for respiration

The energy transferred during respiration supplies all the energy needs for living processes in the cells:

- Living cells need energy to carry out the basic functions of life. They build up large molecules from smaller ones to make new cell material. Much of the energy transferred in respiration is used for these 'building' activities (synthesis reactions). Energy is also transferred to break down larger molecules to smaller ones, both during digestion and within the cells themselves.
- In animals, energy from respiration is transferred to make muscles contract. Muscles are working all the time in your body. Even when you sleep, your heart beats, you breathe, and your stomach churns. All muscular activities require energy.
- Mammals and birds maintain a constant internal body temperature almost regardless of the temperature of their surroundings. On cold days energy transferred from respiration helps you to stay warm, while on hot days you sweat and transfer energy to your surroundings to keep your body cool.
- In plants, energy from respiration is transferred to move mineral ions such as nitrates from the soil into root hair cells. It is also transferred to convert sugars, nitrates, and other nutrients into amino acids, which are then built up into proteins.

- 1** **a** Give the word equation for aerobic respiration. [2 marks]
- b** Give the symbol equation for aerobic respiration. [2 marks]
- c** Explain why muscle cells have many mitochondria while fat cells have very few. [4 marks]
- 2** You need a regular supply of food to provide energy for your cells. If you don't get enough to eat, you become thin and stop growing. As a result, you don't want to move around and you start to feel cold.
  - a** Name the three main uses of the energy transferred in your body during aerobic respiration. [3 marks]
  - b** Suggest how this explains the symptoms of starvation described above. [4 marks]
- 3** Plan an experiment to show that oxygen is taken up and carbon dioxide is released during aerobic respiration. [6 marks]

## Synoptic links

You learnt about mitochondria in Topic B1.2, and about adaptations of active cells in Topic B1.4. You can find out more about active transport and the movement of mineral ions into root hair cells in Topic B1.9, about the use of energy in Topics B18.8, and B18.9, and about temperature control in Topic B12.1.



**Figure 2** When the weather is cold birds like this American robin use up a lot of food for respiration just to keep warm. Giving them extra food supplies during the winter can therefore mean the difference between life and death

## Key points

Cellular respiration is an exothermic reaction that occurs continuously in living cells.

- Aerobic respiration is written as:  
 $\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$  (energy transferred to the environment).
- The energy transferred supplies all the energy needed for living processes.

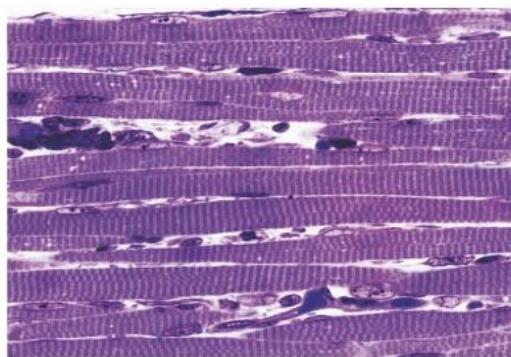


# B9.2 The response to exercise

## Learning objectives

After this topic, you should know:

- how your body responds to the increased demands for energy during exercise.



**Figure 1** All the work done by your muscles is based on these special protein fibres, which need energy from respiration to contract – magnification  $\times 570$

## Go further

Slow twitch muscle fibres rely on aerobic respiration and give endurance. Fast twitch muscle fibres rely on anaerobic respiration and are good for sprinting.

## Study tip

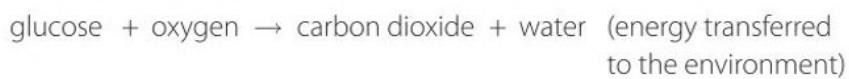
You need to be clear about:

- the difference between the rate and the depth of breathing
- the difference between the breathing rate and the rate of respiration.

Your muscles require a lot of energy to carry out their functions. They move you around and help support your body against gravity. Your heart is made of muscle and pumps blood around your body. The movement of food through your digestive system depends on muscles too.

Muscle tissue is made up of protein fibres that contract when energy is transferred from respiration. Muscle fibres need a lot of energy to contract. They contain many mitochondria to carry out aerobic respiration and transfer the energy needed. Muscle fibres usually occur in big blocks or groups, which contract to cause movement. They then relax, which allows other muscles to work.

Your muscles also store glucose as the carbohydrate **glycogen**. Glycogen can be converted rapidly back to glucose to use during exercise. The glucose is used in aerobic respiration to transfer the energy needed to make your muscles contract:



## The response to exercise

Even when you are not moving about, your muscles use up a certain amount of oxygen and glucose. However, when you begin to exercise, many muscles start contracting harder and faster. As a result, they need more glucose and oxygen for respiration. During exercise the muscles also produce increased amounts of carbon dioxide. This needs to be removed for muscles to keep working effectively.

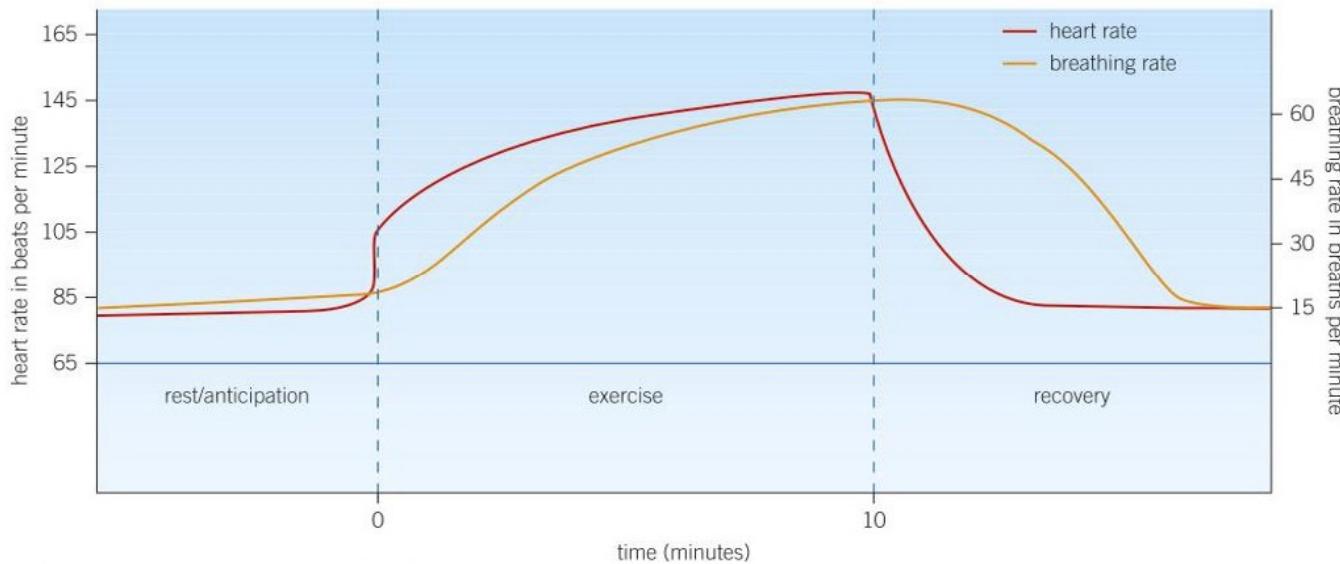
During exercise, when muscular activity increases, several changes take place in your body:

- Your heart rate increases and the arteries supplying blood to your muscles dilate (widen). These changes increase the flow of oxygenated blood to your exercising muscles. This in turn increases the rate of supply of oxygen and glucose for the increased cellular respiration rate needed. It also increases the rate that carbon dioxide is removed from the muscles.
- Your breathing rate increases and you breathe more deeply. This means you breathe more often and also bring more air into your lungs each time you breathe in. The rate at which oxygen is brought into your body and picked up by your red blood cells is increased, and this oxygen is carried to your exercising muscles. It also means that carbon dioxide can be removed more quickly from the blood in the lungs and breathed out.
- Glycogen stored in the muscles is converted back to glucose, to supply the cells with the fuel they need for increased cellular respiration.

In this way, the heart rate and breathing rate increase during exercise to supply the muscles with what they need and remove the extra waste produced. Cellular respiration increases to supply the muscle cells with the increased levels of energy needed for contraction during exercise. The increase in your breathing and heart rate is to keep up with the demands of the cells.

## Synoptic links

You learned about the heart in Topic B4.3, and about the lungs and breathing in Topic B4.4.



**Figure 2** The changes measured in the heart and breathing rate before, during, and after a period of exercise

**Table 1** The heart and lung functions change during exercise whether you are fit or not

	Unfit person	Fit person
amount of blood pumped out of the heart during each beat at rest in $\text{cm}^3$	64	80
volume of the heart at rest in $\text{cm}^3$	120	140
resting breathing rate in breaths per min	14	12
resting pulse rate in beats per min	72	63

**1** Using Figure 2 and Table 1:

- a Describe the effect of exercise on the:
- heart rate of a fit person [3 marks]
  - breathing rate of a fit person. [3 marks]

- b Use Table 1 to explain the difference in heart rate between a fit person and an unfit person. [4 marks]

**2** a Give the function of glycogen.

- b Explain why muscles contain a store of glycogen but most other tissues of the body do not. [5 marks]

**3** a Describe an experiment to test the fitness levels of your classmates. Include a method that your classmates could follow. [6 marks]

b Explain what you would expect the results to be and why. [4 marks]

## Key points

- The energy that is transferred during respiration is used to enable muscles to contract.
- During exercise the human body responds to the increased demand for energy.
- Body responses to exercise include:
  - an increase in the heart rate, in the breathing rate and in the breath volume
  - glycogen stores in the muscles are converted to glucose for cellular respiration
  - the flow of oxygenated blood to the muscles increases.
- These responses act to increase the rate of supply of glucose and oxygen to the muscles and the rate of removal of carbon dioxide from the muscles.



# B9.3 Anaerobic respiration

## Learning objectives

After this topic, you should know:

- why less energy is transferred by anaerobic respiration than by aerobic respiration
- (H) what is meant by an oxygen debt
- that anaerobic respiration takes place in lots of different organisms, including plants, bacteria, and fungi.

Your everyday muscle movements use energy transferred by aerobic respiration. However, when you exercise hard, your muscle cells may become short of oxygen. Although you increase your heart and breathing rates, sometimes the blood cannot supply oxygen to the muscles fast enough. When this happens, energy from the breakdown of glucose can still be transferred to the muscle cells. They use **anaerobic respiration**, which takes place without oxygen.

## Anaerobic respiration

Anaerobic respiration is not as efficient as aerobic respiration because the glucose molecules are not broken down completely. In animal cells the end product of anaerobic respiration is **lactic acid** instead of carbon dioxide and water. Because the breakdown of glucose is incomplete, far less energy is transferred than during aerobic respiration.

Anaerobic respiration:



## Muscle fatigue

Using your muscle fibres vigorously for a long time can make them become fatigued and they stop contracting efficiently. One cause of this muscle fatigue is the build-up of lactic acid, produced by anaerobic respiration in the muscle cells. The build up of lactic acid in the muscles as a result of anaerobic respiration creates an **oxygen debt**.

For example, repeated movements can soon lead to anaerobic respiration in your muscles – particularly if you’re not used to the exercise. If you are fit, your heart and lungs will be able to keep a good supply of oxygen going to your muscles while you exercise for a relatively long time. If you are unfit, your muscles will run short of oxygen much sooner.



**Figure 1** Training hard is the simplest way to avoid anaerobic respiration. When you are fit, you can get oxygen to your muscles and remove carbon dioxide more efficiently

### Making lactic acid

Repeat a single action many times. For example, you could step up and down, lift a weight or clench and unclench your fist. You will soon feel the effect of a build-up of lactic acid in your muscles as they begin to ache.



## Oxygen debt

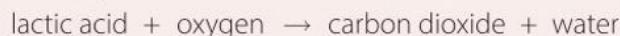
If you have been exercising hard, you often carry on puffing and panting for some time after you stop. The length of time you remain out of breath depends on how fit you are. Why do you carry on breathing fast and deeply when you have stopped using your muscles?

The waste lactic acid you produce during anaerobic respiration is a problem. You cannot simply get rid of lactic acid by breathing it out as you can with carbon dioxide. As a result, when the exercise is over, lactic acid has to be converted back to glucose in the liver (see B9.4). The glucose produced may then be broken down to produce carbon dioxide and water. This process needs oxygen.

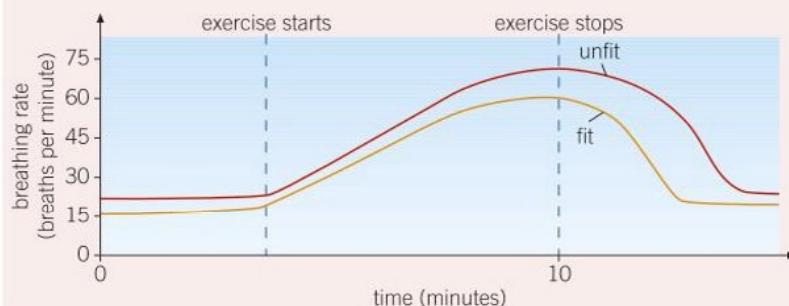
The amount of oxygen needed to convert the lactic acid to glucose is known as the oxygen debt. After a race, your heart rate and breathing rate stay high to supply the extra oxygen needed to pay off the oxygen debt. The bigger the debt (the larger the amount of lactic acid), the longer you will puff and pant.

Higher

Oxygen debt repayment:



In a 100 m sprint, some athletes do not breathe at all. This means that the muscles use the oxygen taken in before the start of the race and then don't get any more oxygen until the race is over. Although the race only takes a few seconds, a tremendous amount of energy is used up, so a big oxygen debt can develop, even if the athletes are very fit.



**Figure 2** Everyone gets an oxygen debt if they exercise hard, but if you are fit you can pay it off faster

### Testing fitness

A good way of telling how fit you are is to measure your resting heart rate and breathing rate. The fitter you are, the lower they will be. This is because the heart and lungs of fit people are bigger and have a better blood supply than those of less-fit people. They are more efficient. Then see what happens when you exercise. The increase in your heart rate and breathing rate, along with how quickly they return to normal, are also ways of finding out how fit you are – or aren't!



## Anaerobic respiration in other organisms

Humans and other animals are not the only living organisms that can respire anaerobically. Plants and microorganisms can also respire without oxygen. However, when plant cells respire anaerobically they do not form lactic acid – they form ethanol and carbon dioxide. Some microorganisms form lactic acid during anaerobic respiration – the bacteria used to form yoghurts, for example. Other microorganisms, including yeast, form ethanol and carbon dioxide. Anaerobic respiration in yeast cells is known as fermentation. People have made use of this for thousands of years. It is a very economically important reaction because it is used globally in the manufacture of bread and alcoholic drinks.



- 1 If you exercise very hard or for a long time, your muscles begin to ache and do not work effectively. Explain why. [4 marks]
- 2 **a** Define anaerobic respiration. [1 mark]
   
**b** Explain how anaerobic respiration differs between animals, plants, and yeast. In each case, explain the benefits to the organism of being able to respire in this way. [6 marks]
   
**c** Write the word equation for anaerobic respiration in animals, plants, and yeast. [3 marks]
- 3 If you exercise vigorously, you often puff and pant for some time after you stop. Explain what is happening. [4 marks]

### Key points

- If muscles work hard for a long time, they become fatigued and don't contract efficiently. If they don't get enough oxygen, they will respire anaerobically.
- Anaerobic respiration is respiration without oxygen. When this takes place in animal cells, glucose is incompletely broken down to form lactic acid.
- The anaerobic breakdown of glucose transfers less energy than aerobic respiration.
- **H** After exercise, oxygen is still needed to convert the accumulated lactic acid into glucose. The amount of oxygen needed is known as the oxygen debt.
- Anaerobic respiration in plant cells and some microorganisms, such as yeast, results in the production of ethanol and carbon dioxide.

# B9.4 Metabolism and the liver

## Learning objectives

After this topic, you should know:

- that metabolism is the sum of all the reactions in a cell or the body of an organism
- (H) how the liver is involved in repaying the oxygen debt

The metabolism of an organism is the sum of all the reactions that take place in a cell or in the body. Some of the energy transferred by respiration reactions in cells simply heats the environment. However, some of it is used by the organism for the continual enzyme-controlled processes of metabolism that make molecules or break them down. It is used to bring about change and movement where needed. As you saw in Topic B9.1, the energy transferred by respiration in animals is also used to enable the muscles to contract. In mammals and birds it is also used to maintain a constant body temperature.

## Synoptic links



You learnt about the reactions that build up carbohydrates, proteins, and lipids in Topic B3.3.

You learnt about the reactions of photosynthesis in Topic B8.1 and Topic B8.3.

## Metabolic reactions

There are hundreds of thousands of metabolic reactions but you don't have to learn them all. Some of the most common metabolic reactions include:

- the conversion of glucose to starch, glycogen, and cellulose
- the formation of lipid molecules from a molecule of glycerol and three fatty acid molecules
- the use of glucose and nitrate ions to form amino acids that are then used to make proteins
- the reactions of respiration
- the reactions of photosynthesis
- the breakdown of excess proteins in the liver to form urea for excretion in the urine by the kidneys.

You have already met a number of these reactions in some detail.



**Figure 1** Many of the metabolic reactions of plants and animals, such as aerobic respiration, are exactly the same, but some, for example photosynthesis, are very different

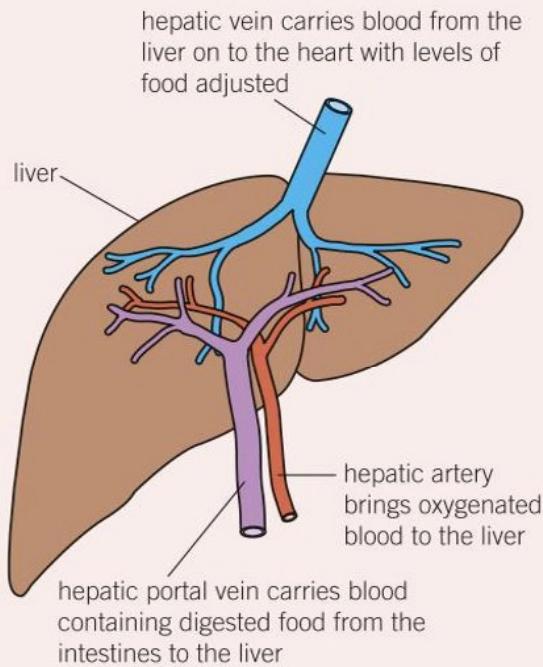
## The role of the liver

Your liver is a large reddish-brown organ that carries out many different functions in your body. Liver cells grow and regenerate themselves very rapidly. The liver is a very active organ with many different metabolic functions. These include:

- detoxifying poisonous substances such as the ethanol from alcoholic drinks
- passing the breakdown products into the blood so they can be excreted in the urine via the kidneys
- breaking down old, worn out blood cells and storing the iron until it is needed to synthesise more blood cells.

## Removing lactic acid

One important role of the liver is in dealing with the lactic acid produced by the muscles during anaerobic respiration. Blood flowing through the muscles transports the lactic acid to the liver where it is converted back into glucose. The oxygen debt is repaid once the lactic acid has been converted back to glucose and the glucose has been completely broken down in aerobic respiration to form carbon dioxide and water. If it isn't needed, the glucose made from the lactic acid may be converted to glycogen and stored in the liver until it is needed.



**Figure 2** Your liver weighs about 1.5 kg and plays a vital role in removing poisons from your body

- 1 What is metabolism? [1 mark]
- 2 Give four examples of metabolic reactions in the body. [4 marks]
- 3 **H** The liver is an organ of respiration. Evaluate this statement. [5 marks]

## Key points

- Metabolism is the sum of all the reactions in the body.
- The energy transferred by respiration in cells is used by the organism for the continual enzyme-controlled processes of metabolism that synthesise new molecules
- Metabolism includes the conversion of glucose to starch, glycogen and cellulose. Metabolism also includes the formation of lipid molecules, and the use of glucose and nitrate ions to form amino acids, which are used to synthesise proteins, and breakdown excess proteins to form urea.
- **H** Blood flowing through the muscles transports lactic acid to the liver where it is converted back to glucose.