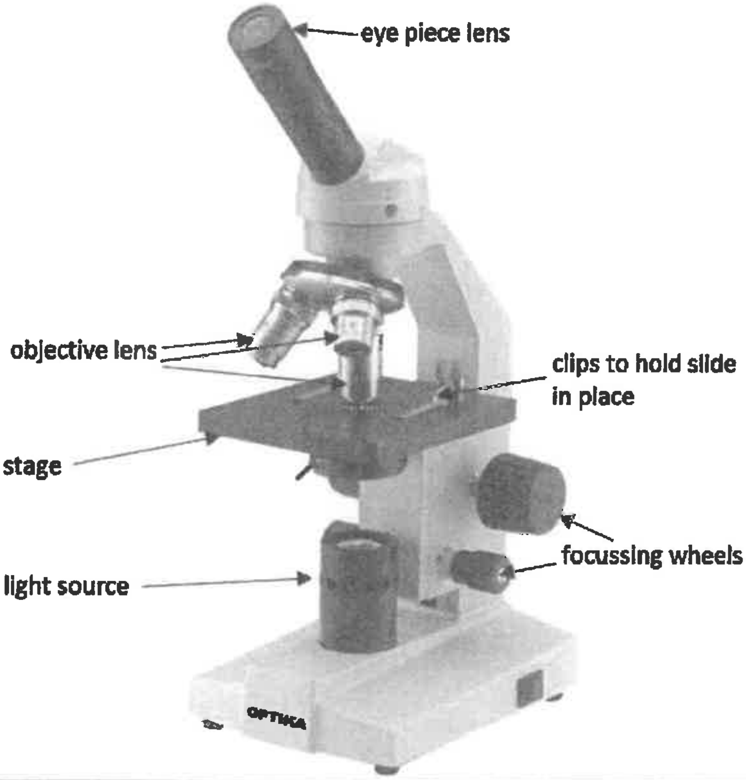
# Double BTEC Science Tasks

# Double BTEC GCSE revision

Microscope core practical




Specification:

| | |
|---|---|
| 1.3 | Explain how changes in microscope technology, including electron microscopy, have enabled us to see cell structures with more clarity and detail than in the past and increased our understanding of the role of sub-cellular structures |
| 1.4 | Demonstrate an understanding of number, size and scale, including the use of estimations and explain when they should be used |
| 1.5 | Demonstrate an understanding of the relationship between quantitative units in relation to cells, including:<br>a milli ($10^{-3}$)<br>b micro ($10^{-6}$)<br>c nano ($10^{-9}$)<br>d pico ($10^{-12}$)<br>**e calculations with numbers written in standard form** |
| 1.6 | *Core Practical: Investigate biological specimens using microscopes, including magnification calculations and labelled scientific drawings from observations* |

# Could be tested on paper one AND paper 2

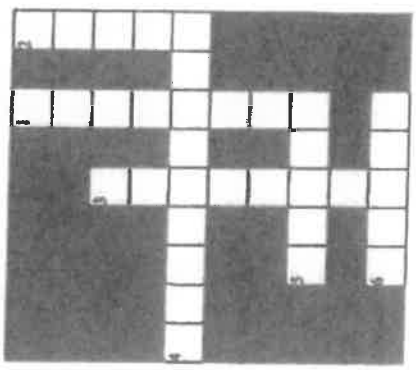
# Watch the video on Moodle and think about these questions……

- What are the two types of lenses called and what are there magnifications?
- Why do you start with the lowest magnification?
- Why is it important that the sample on the slide is very thin (i.e. one cell thick)?
- What is the stain for?
- Why is a cover slip used?

2 Use these clues to complete the crossword.

**Across**
4 Lens closest to the slide.
5 The specimen is placed on this.
6 You need this to see something

**Down**
1 Lens that you look down.
2 What the slide is placed on.
3 A wheel to make the image clear.



3. Write down the instructions you would have to follow to correctly use a microscope.

## How to use a microscope

1) Take a very **thin** specimen and place on a clean slide e.g. a one cell thick peel from an onion, or peel dried nail varnish off the bottom of a leaf. The specimen has to be thin because

2) **Stain** the specimen with a suitable **stain** e.g. iodine or toluidine blue. This is because

3) Place a cover slip on top of the specimen. This is because

4) Turn the microscope light on. Place the slide on the stage. Use the **objective lens** with the lowest magnification e.g. x 4.

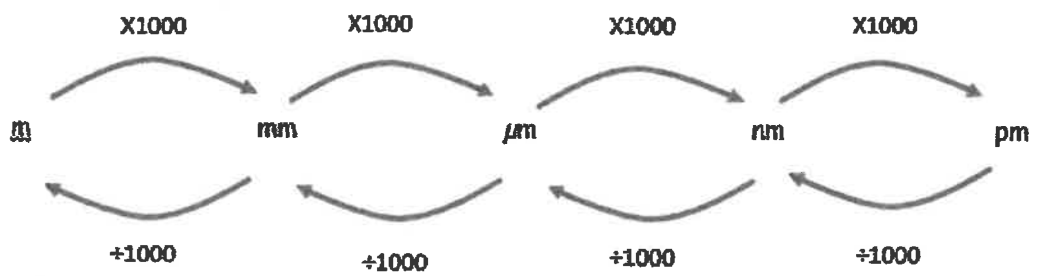
5) Look through the **eyepiece lens** (x10 magnification). This means the specimen is magnified x 40 (why?)

6) Use the focussing wheel to bring the specimen into focus and get a clear image.

7) Move to a higher magnification by changing to x 10 **objective lens**. This gives magnification of

8) If needed move to a higher magnification by changing to x 40 **objective lens**. This gives magnification of

**How to convert units:**




What about cm?

| cm | mm | µm | nm | pm |
|---|---|---|---|---|
| 0.01 | | | | |
| | 3 | | | |
| | | 7000 | | |
| | | | 7542000 | |
| 2.4 | | | | |

**Key terms:**

**Magnification: The number of times greater that an image is than the actual object**

**Resolution / resolving power: is the minimum distant apart that two objects can be in order for them to appear as separate items.**

# What sort of exam questions could they ask?

- Apparatus questions
- Method questions
- Calculation questions
- cell ultrastructure questions
- Mitosis/meiosis questions

- We are now going to go through some past exam questions
- 1 mark= 1 minute

**Worked Example: Find the actual diameter of a bacteria cell**

| Image size: | Magnification: X5000 | Actual size: µm |
|---|---|---|

Each division = 1mm

[illegible] tion to [illegible]

Step 1. Magnification = 5000

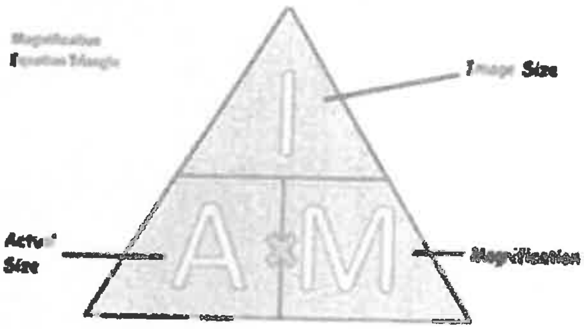
Step 2. Count the size of the bacteria (mm) – 10mm

Step 3. Do the calculation = 10 ÷ 5000

Step 4: 10 ÷ 5000 0.002mm

Step 5: Convert mm into µm using the table 0.001mm = 1µm so 0.002mm must be 2 µm.

<u>ANSWER = Size of bacteria is 2 µm</u>

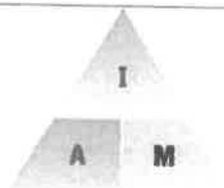



1. Magnification = image size ÷ actual size.
2. Actual size = image size ÷ magnification.
3. Image size = actual size x magnification.

<u>Conversion Table: mm to µm</u>

| Length in mm | Length in µm |
|---|---|
| 1 | 1000 |
| 0.1 | 100 |
| 0.01 | 10 |
| 0.001 | 1 |

# Magnification




$$\text{Magnification} = \frac{\text{Image size}}{\text{Actual size}}$$

**Step 1)**

Measure the image size using a ruler in millimetres (mm)

**Step 2)**

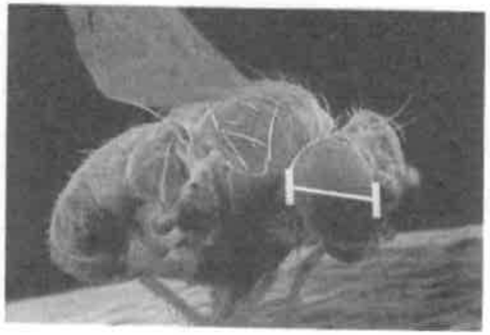
Convert the millimetres (mm) into micrometres (µm)

**Step 3)**

Divide your answer by the actual size

## Question 1

This is a fly. Its actual eye size is 1,000µm. What is the magnification?



1) Length of eye is ________ mm

2) _______ mm x1000 = _________ µm

3) Image size = _________ µm

4) Magnification = Image ÷ Actual

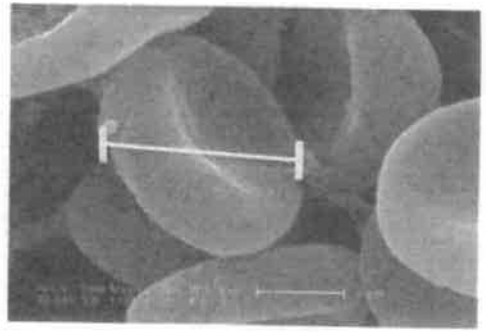
Magnification = _____ µm ÷ _____ µm

Magnification = ________

The picture shows the eye magnified (zoomed in) by ________ times.

## Question 2

This is a red blood cell. Its actual size is 300µm. What is the magnification?



1) Length of cell is ________ mm

2) _______ mm x1000 = _________ µm

3) Image size = _________ µm

4) Magnification = Image ÷ Actual

Magnification = _____ µm ÷ _____ µm

Magnification = ________

The picture shows the cell magnified (zoomed in) by ________ times.

## Question 3

This is a snowflake. Its actual height is 700µm. What is the magnification?

1) Length of snowflake is ________ mm

2) _______ mm x1000 = _________ µm

3) Image size = _________ µm

4) Magnification = Image ÷ Actual

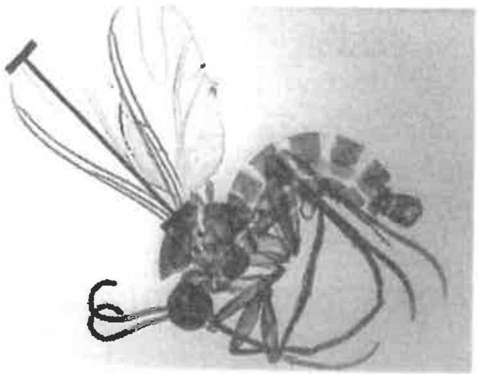
Magnification = _____ µm ÷ _____ µm

Magnification = ________

The picture shows the snowflake magnified (zoomed in) by ________ times.

## Question 4

This is an insect. Its wings are 2,500µm. What is the magnification?



1) Length of wing is ________ mm

2) _______ mm x1000 = _________ µm

3) Image size = _________ µm

4) Magnification = Image ÷ Actual

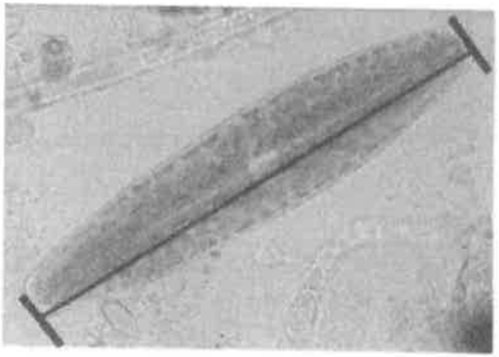
Magnification = _____ µm ÷ _____ µm

Magnification = ________

The picture shows the wing magnified (zoomed in) by ________ times.

## Question 5

This is a chloroplast. Its actual length is 50µm. What is the magnification?



1) Length of chloroplast is ________ mm

2) _______ mm x1000 = _________ µm

3) Image size = _________ µm

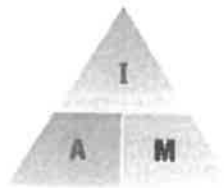
4) Magnification = Image ÷ Actual

Magnification = _____ µm ÷ _____ µm

Magnification = ________

The picture shows the chloroplast magnified (zoomed in) by ________ times.

## Actual Size




$$\text{Actual size} = \frac{\text{Image size}}{\text{Magnification}}$$

**Step 1)**

Measure the image size using a ruler in millimetres (mm)

**Step 2)**

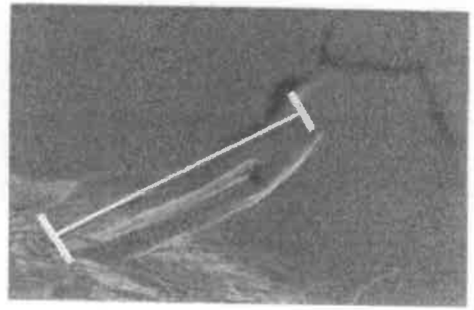
Convert the millimetres (mm) into micrometres (µm)

**Step 3)**

Divide your answer by the magnification

## Question 1

This is a mosquito stinger. The magnification is x4. What is the actual size?



1) Length of stinger is ________ mm

2) _______ mm x1000 = _________ µm

3) Image size = _________ µm

4) Actual size = Image ÷ Magnification

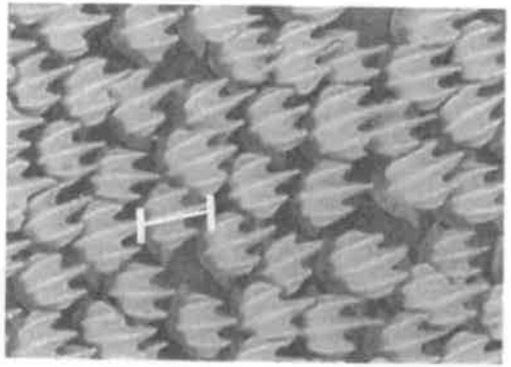
Actual size = ______ µm ÷ _____

Actual size = ________

The actual size of this stinger is _____ µm. We can see it because it has been magnified.

## Question 2

This is shark skin. It is made of teeth. The magnification is x50. What is the actual size of 1 tooth?



1) Length of tooth is ________ mm

2) _______ mm x1000 = __________ µm

3) Image size = __________ µm

4) Actual size = Image ÷ Magnification

Actual size = ______ µm ÷ _____

Actual size = ________

The actual size of this tooth is _____ µm. We can see it because it has been magnified.

## Question 3

This is a grain of salt. The magnification is x100. What is the actual size of the salt?


1) Size of salt is ________ mm

2) _______ mm x1000 = __________ µm

3) Image size = __________ µm

4) Actual size = Image ÷ Magnification

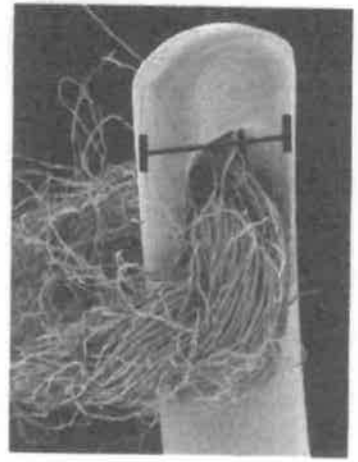
Actual size = ______ µm ÷ _____

Actual size = ________

The actual size of this salt is _____ µm. We can see it because it has been magnified.

## Question 4

This is a needle and thread. The magnification is x4. What is the actual size of the needle?



1) Size of needle is ________ mm

2) _______ mm x1000 = __________ µm

3) Image size = __________ µm

4) Actual size = Image ÷ Magnification

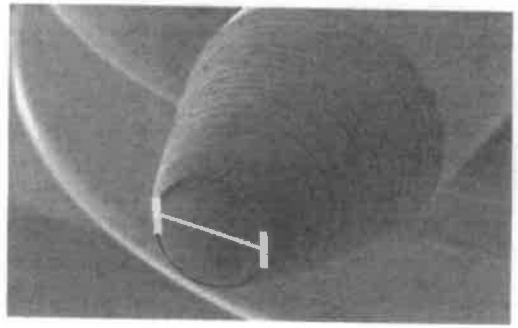
Actual size = ______ µm ÷ _____

Actual size = ________

The actual size of this needle is _____ µm. We can see it because it has been magnified.

## Question 5

This is a ballpoint pen. The magnification is x20. What is the actual size of the ballpoint pen?



1) Size of pen is ________ mm

2) _______ mm x1000 = __________ µm

3) Image size = __________ µm

4) Actual size = Image ÷ Magnification

Actual size = ______ µm ÷ _____

Actual size = ________

The actual size of this ballpoint pen is _____ µm. We can see it because it has been magnified.

## Questions

Q1. The diagram shows the steps involved in making a slide to observe mitosis in plant tissue.

| | |
|---|---|
| step 1 | a small sample of tissue is removed from a plant |
| step 2 | the plant tissue is placed in a weak acid solution |
| step 3 | a stain is added to the plant tissue |
| step 4 | the stained plant tissue is squashed onto a slide |
| step 5 | a cover slip is placed over the stained plant tissue |
| step 6 | the stained plant tissue is observed using a microscope |

(i) To observe mitosis, the plant tissue should be removed from the

(1)

☐ A middle of the root

☐ B centre of the stem

☐ C middle of the leaf cell

☐ D tip of the root

(ii) State why the stain is added to the plant tissue in step 3.

(1)

..................................................................................................................

The microscope has an eyepiece lens with a ×10 magnification and three objective lenses: ×4, ×10 and ×40.

Describe the best method of using the microscope to focus on the plant tissue and reach a magnification of ×400.
(3)

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(ii) Figure 4 shows a magnified onion cell.

The actual width of this onion cell is 100 µm.


Figure 4

Calculate the magnification of this onion cell.

(2)

magnification = ..................................

(c) Figure 9 shows a root tip with cells in different stages of mitosis.

The image was magnified 400×.

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Figure 9

Explain how a magnification of 400× can be obtained using the lenses on a light microscope.

(2)

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(Total for Question 4 = 9 marks)

DO NOT WRITE IN THIS AREA

DO NOT WRITE IN THIS AREA

4 (a) A student cut a piece of onion and placed it on a microscope slide.

The student then placed this slide on the stage of a light microscope and looked through the eyepiece.

No cells could be seen in the piece of onion.

Explain **two** ways this method could be improved to see details of the onion cells.

(4)

1. ....................................................................................................

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2. ....................................................................................................

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(iv) The cells in Figure 4 were heated in hydrochloric acid.

State **two** safety precautions that should be taken when heating hydrochloric acid.

(2)

1. ....................................................................................................

....................................................................................................

2. ....................................................................................................

....................................................................................................

(c) Explain **one** advantage of using an electron microscope to observe plant cells.

(2)

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**(Total for Question 4 = 12 marks)**



(ii) The actual length of the red blood cell from a turtle is 20.5 μm.

Calculate the length of the magnified image of the red blood cell of the turtle when magnified 400×.

(2)

.................................................... μm

(iii) The width of the human red blood cell, when magnified 400×, is 3.08 mm.

Calculate the actual width of the cell and show your answer in standard form.

(2)

.................................................... mm

6 A student compared the number of stomata on the upper and lower surfaces of a leaf.

She completed a leaf peel as shown in Figure 12.

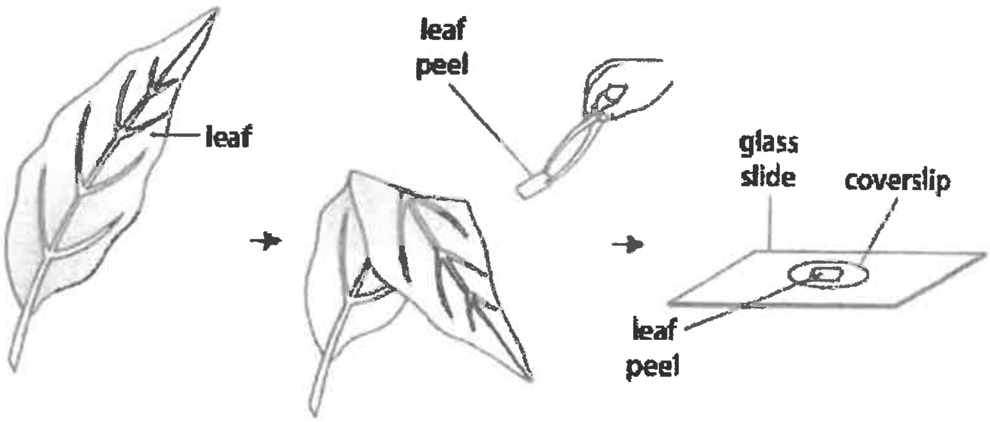



**Figure 12**

The layer of nail varnish shows an impression of the cells on the surface of the leaf.

(a) (i) State why a coverslip is placed on top of the leaf peel.

(1)

(ii) Explain why the leaf peel rather than the whole leaf was viewed with a microscope.

(2)

# SC2c Paper chromatography

Specification reference: C2.7; C2.9; C2.10

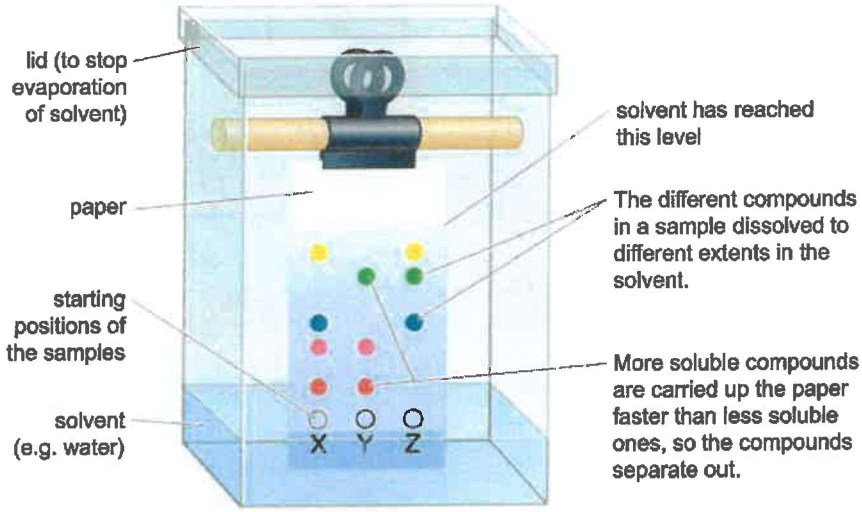
## Progression questions

- How can chromatography be used to separate mixtures?
- What are the differences between mixtures and pure substances on a chromatogram?
- How do you calculate an $R_f$ value?

**A** Experts restoring an old painting – they need to know what substances were mixed together to produce the paints used by the original artist.

Inks, paints and foods often contain mixtures of coloured compounds. **Chromatography** can be used to find out which coloured compounds the mixture contains. The type of chromatography used to analyse the substances in old oil paintings requires expensive machinery.

**Paper chromatography** is a simpler technique that works because some compounds dissolve better in a solvent than others. When a solvent moves along a strip of paper, it carries the different substances in the mixture at different speeds, so they are separated. The solvent is called the **mobile phase**. The paper contains the **stationary phase**, through which the solvent and dissolved substances move. The paper with the separated components on it is called a **chromatogram**.




**B** paper chromatography

The **$R_f$ value** is the distance the compound has risen divided by the distance the solvent has risen. Both measurements are made from the starting positions of the samples on the paper.

$$R_f = \frac{\text{distance moved by the spot}}{\text{distance moved by the solvent}}$$

The $R_f$ value of a particular compound does not change if the chromatography conditions used remain the same.

5th **1 a** How many different compounds are in substance X in diagram B?

6th **b** For mixture Y, explain why the green spot is higher than the red spot.

**2** Look at diagram B again. Explain why:

5th **a** the labels for substances X, Y and Z are written in pencil, not ink

5th **b** the starting positions for the different substances are above the level of solvent in the container.

6th **3** One of the coloured compounds in diagram B has an $R_f$ value of 0.1. Explain which compound this is likely to be.

## Worked example

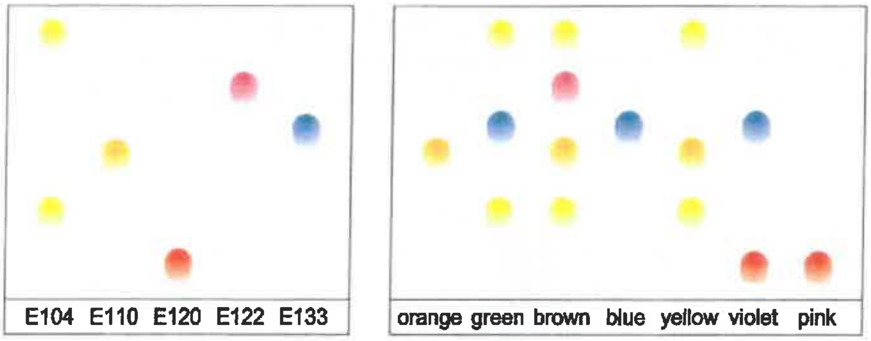
In diagram B, the pink spots have moved 4 cm and the solvent has moved 10 cm along the paper. Calculate the $R_f$ value of this pink compound:

$R_f = \frac{4}{10} = 0.4$

A compound never rises as fast as the solvent, so $R_f$ values are always less than 1. If you calculate an $R_f$ value bigger than 1, you've made a mistake.

Paper chromatography can be used to:

- distinguish between pure and impure substances
- identify substances by comparing the pattern on the chromatogram with the patterns formed by known substances
- identify substances by calculating their $R_f$ values.




**C** The chromatogram on the left was done using known substances. The chromatogram on the right shows that the orange and blue sweets contain single dyes.

**4** In diagram B, the yellow spots have moved 9 cm and the solvent has moved 10 cm. Calculate the $R_f$ value of the yellow substance.

**5** In diagram C, the chromatogram on the left shows some food dyes found in sweets. The chromatogram on the right shows the results for some sweets.

**a** Which sweets contain just one dye?

**b** Which dyes are in the yellow sweets?

**c** What is the colour of the most soluble dye?

## Did you know?

In 1983, many national newspapers paid a lot of money to publish diaries allegedly written by Adolf Hitler. However, scientists used chromatography to analyse the inks in the diaries and found that they were not available during Hitler's lifetime – the diaries were fake.


**D** Chromatography can be used to help identify substances at crime scenes.

## Exam-style question

Two dyes have the same $R_f$ values when tested using chromatography. Explain whether this means they are the same dye or not. *(3 marks)*

## Checkpoint

How confidently can you answer the Progression questions?

### Strengthen

**S1** The police have taken four orange lipsticks from suspects. Explain the steps needed to find out if one of the lipsticks could have made a mark at a crime scene.

### Extend

**E1** A laboratory produces a list of $R_f$ values for food colourings. Explain why $R_f$ values are used and what other information is needed for these $R_f$ values to be useful.

# SC1a States of matter

**Specification reference: C2.1; C2.2; C2.3; C2.4**

## Progression questions

- What are particles like in substances in the solid, liquid and gas states?
- What changes happen to particles during the different changes of state?
- How do you decide what state a substance will be in at a given temperature?

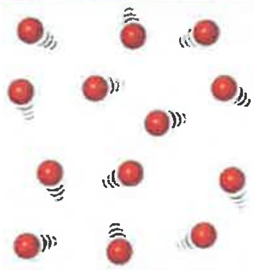
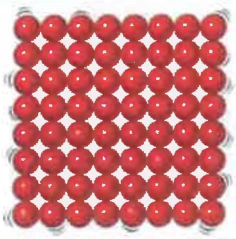
**A** This 'ice hotel' is made entirely from ice and snow – these are both water in the solid state.

The three **states of matter** are solid, liquid and gas. For example, water can exist in the solid state as ice, or in the familiar liquid state, or in the gas state as steam or water vapour.

### The particle model

Some **particles** are large enough to see, like the dust on a computer screen. Others, like **atoms** and **molecules**, are far too small for you to see. When chemists discuss particles, they usually mean these very small particles.

The **particle model** explains state changes in a substance in terms of the arrangement, movement and energy stored in its particles.

| State | Particle diagram | Arrangement of particles | Movement of particles |
|---|---|---|---|
| Gas |  | random<br>far apart | fast in all directions |
| Liquid |  | random<br>close together | move around each other |
| Solid |  | regular<br>close together | vibrate about fixed positions |

**B** Particles in the solid state contain the smallest amount of stored energy; particles in the gas state contain the most.

#### Did you know?

Science recognises 16 different types of ice, depending on the arrangement of the water molecules. A type called amorphous ice is found in space (such as on comets). A type called Ice IV is what you'll find in a kitchen freezer, here on Earth.

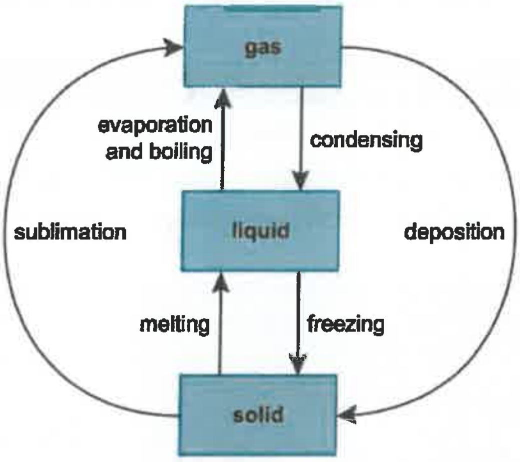
**1** Describe the difference in the arrangements of particles in a solid and in a liquid.

**2** Describe the difference in the movement of particles in a liquid and in a gas.

## State changes

State changes are **physical changes**. They can be reversed, and the **chemical properties** of the substance do not change. This is because the particles themselves do not change – only their arrangement, movement and amount of stored energy.

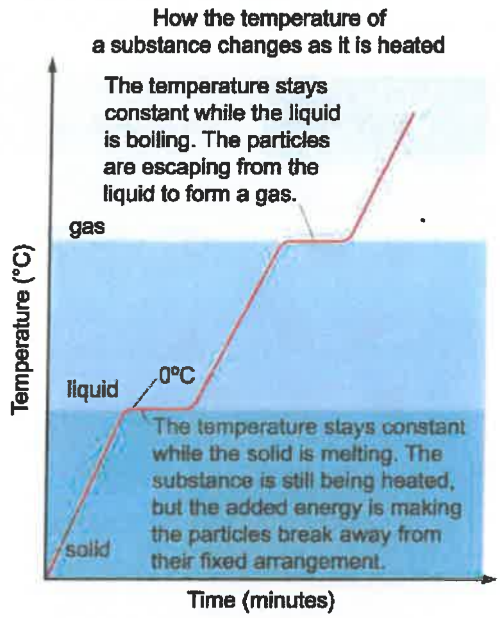
3 State the meaning of the terms 'sublimation' and 'deposition'.




**C** the interconversions between the three states of matter

Particles are attracted to one another by weak forces of attraction. There are many of these forces in a solid. Some of these are overcome during melting. The remaining **attractive forces** between particles in a liquid are overcome during evaporation and boiling (when a substance is evaporating as fast as it can). For this to happen, energy must be transferred from the surroundings to the particles. This is why you heat ice to melt it, and why you boil water in a kettle. Diagram D shows how the temperature changes when water in the solid state is heated until it reaches the gas state.

Some attractive forces form between particles during condensing, and many attractive forces are formed during freezing. For this to happen, energy must be transferred from the particles to the surroundings. This is why water vapour turns into water droplets on a cold window, and why you put water in a freezer to make ice.




**D** a heating curve for water

You can predict the state of a substance if you know its temperature, and its **melting point** and **boiling point**. If the temperature is:

- below the melting point, the substance is solid
- between the melting point and boiling point, the substance is liquid
- above the boiling point, the substance is gas.

4 Describe how you can see from a 'heating curve' (such as diagram D) that a substance is changing state.

5 Explain what happens to the particles when a substance melts.

6 The melting point of gallium is 29.8 °C and its boiling point is 2204 °C. Predict its state at 25 °C, 100 °C and at 2205 °C.

### Exam-style question

Camping gas is used by campers and hikers. It is a mixture of propane and butane. Explain, in terms of the arrangement of fuel particles, why camping gas is stored in cylinders as a liquid rather than as a gas.

*(2 marks)*

### Checkpoint

How confidently can you answer the Progression questions?

#### Strengthen

**S1** Draw a diagram to show the states of matter. On your diagram, name each state change and describe what happens to the particles as it happens.

#### Extend

**E1** Explain why the arrangement, movement and energy of particles change during changes of state.

# SC2a Mixtures

Specification reference: C2.5; C2.6

## Progression questions

- What is the difference between a pure substance and a mixture?
- What happens to its particles when a solid melts?
- How do melting points allow you to spot the differences between pure substances and mixtures?

**A** You can tell this gold bar is very nearly pure because of the '999.9' stamped on it. A number lower than 1000 on this 'fineness' scale means it is impure.

The composition (make-up) of a **pure** substance:

- cannot be changed
- is the same in all parts of a piece of the substance.

So, for example, pure gold contains only gold atoms.

**1** Which type of atoms are found in a piece of pure silver?

**2** State what is meant by the term 'impure'. Explain what the term 'impure' means.

Gold is an **element** and can be pure, but **compounds** can also be pure. The sugar we use at home is a compound called sucrose. It contains carbon, hydrogen and oxygen atoms chemically bonded together to form sucrose molecules. You cannot change the composition of pure sucrose.

### Did you know?

The purest gold ever was produced in 1957 and was 999.999 on the fineness scale.

Gold purity is still often measured on the older carat scale, where 24 carat gold is pure gold.

**3** **a** Describe what a mixture of carbon, hydrogen and oxygen might look like.

**b** Describe how you would separate marbles from sand.

**4** Oxygen can be removed from air by cooling. Explain why this would not be possible if air were not a mixture.

**B** Pure sucrose is always sucrose, no matter how finely it is ground down.

A pure substance has the same fixed composition in all its parts and so we can't separate it into other substances using physical methods (such as filtering or picking bits out).

A **mixture** contains elements and/or compounds that are not chemically joined together. You *can* use physical processes to separate mixtures into different substances.

A mixture does not have a fixed composition. For example, air is a mixture of gases. When students sit in a classroom, they use up oxygen and breathe out carbon dioxide and so the composition of the air in the room changes. We still call it 'air', but because air is a mixture its composition can change.

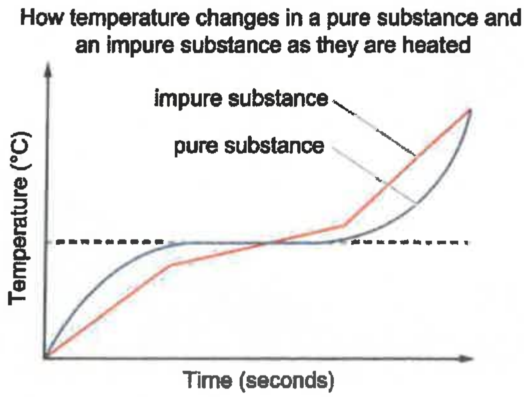
## Melting points

When a solid melts, its particles gain enough energy to overcome the weak forces of attraction between them. They move further away from one another and the solid becomes a liquid. The temperature at which this happens is the **melting point**. This is an example of a **physical property** (how a substance responds to forces and energy).

A pure substance has the same composition in every part of it, and so its physical properties are the same in every part. So, all of a pure substance will melt at the same temperature until all the substance has changed state. The melting point of pure gold is 1063 °C and the melting point of oxygen is −218 °C.

5⁺ **5** What is the freezing point of pure oxygen?

**C** This sweet is a mixture and so does not have a sharp melting point.




**D** heating curves for a pure substance and a mixture

The sweet shown in photo C has a liquid centre. The whole sweet melts over a *range* of temperatures and not all the parts melt and become liquid at the same time. This is what happens in mixtures – they do not have fixed, sharp melting points.

| Substance | Melting temperatures (°C) |
|---|---|
| lead–tin alloy | 183 to 258 |
| argon | −189 |
| carbon monoxide | −205 |

**6** The table shows some melting temperatures.

5⁺ **a** Identify which substances are mixtures and which are pure.

7⁺ **b** Sketch a cooling curve for each of the three examples and explain their shapes.

**Exam-style question**

Explain why mixtures melt over a range of temperatures but pure substances have precise melting points. *(2 marks)*

**Checkpoint**

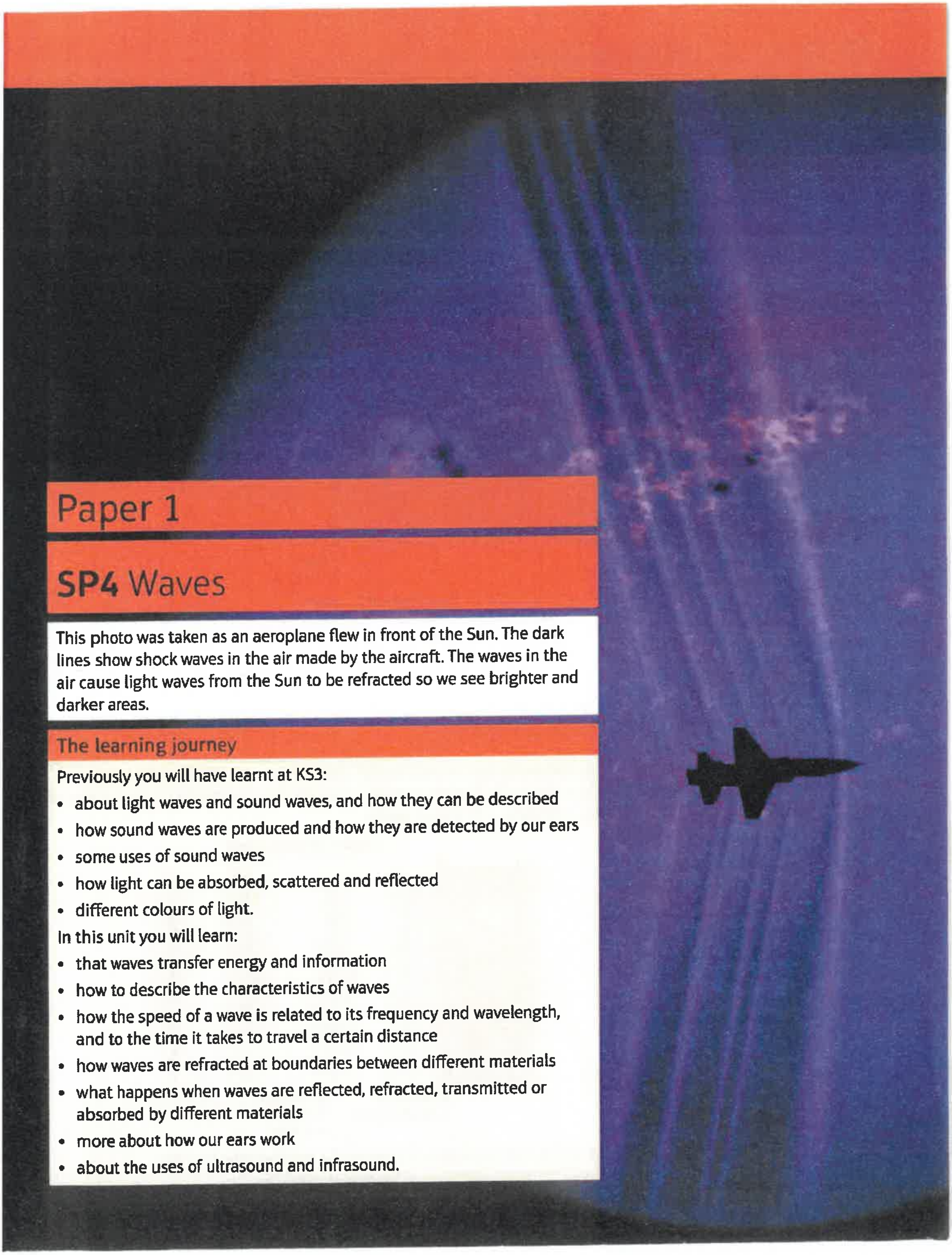
How confidently can you answer the Progression questions?

**Strengthen**

**S1** List the ways in which pure substances are different from mixtures.

**Extend**

**E1** A piece of gold jewellery is 750 on the fineness scale. Would you expect the jewellery to have a sharp melting temperature? Explain your answer.



# Paper 1

## SP4 Waves

This photo was taken as an aeroplane flew in front of the Sun. The dark lines show shock waves in the air made by the aircraft. The waves in the air cause light waves from the Sun to be refracted so we see brighter and darker areas.

### The learning journey

Previously you will have learnt at KS3:

- about light waves and sound waves, and how they can be described
- how sound waves are produced and how they are detected by our ears
- some uses of sound waves
- how light can be absorbed, scattered and reflected
- different colours of light.

In this unit you will learn:

- that waves transfer energy and information
- how to describe the characteristics of waves
- how the speed of a wave is related to its frequency and wavelength, and to the time it takes to travel a certain distance
- how waves are refracted at boundaries between different materials
- what happens when waves are reflected, refracted, transmitted or absorbed by different materials
- more about how our ears work
- about the uses of ultrasound and infrasound.

# SP4a Describing waves

Specification reference: P4.1; P4.2; P4.3; P4.4; P4.5

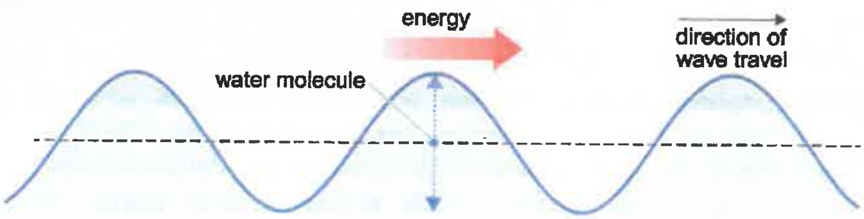
## Progression questions

- What do waves transfer?
- How can we describe waves?
- What is the difference between a longitudinal wave and a transverse wave?

**A** Energy from waves demolished part of the railway line and road at Dawlish in Devon in 2014.

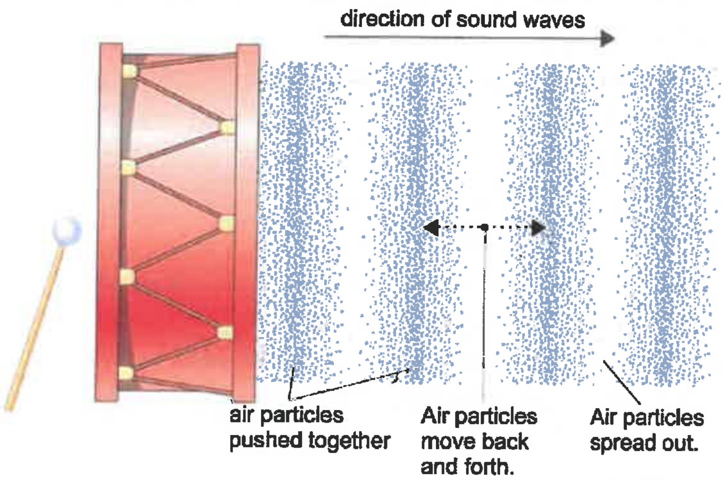
Sea **waves** transfer energy to the shore. When waves hit the land, the energy is transferred to the land and can wear it away.

Waves on the surface of water are **transverse** waves. Particles in the water move up and down as a wave passes – the particles are not carried to the shore.




**B** In a transverse wave the particles move up and down at right angles to the direction the wave is moving.

**Sound waves** also transfer energy. Sound waves are **longitudinal** waves. Particles in the material through which the wave is travelling move backwards and forwards as the wave passes.




**C** Sound waves are longitudinal waves. The particles move back and forth in the same direction as the wave is travelling.

**1** If the water in a wave moved in the same direction as the energy, what would happen to the water in a swimming pool if you made waves at one end?

**2** Particles in a sound wave move in the same direction as the wave is travelling. Explain why loudspeakers do not move all the air in a room away from them.

Earthquakes and explosions produce **seismic waves** that travel through the Earth. Solid rock material can be pushed and pulled (longitudinal seismic waves) or moved up and down, or side to side (transverse seismic waves).

**Electromagnetic waves** (such as light, radio waves, microwaves) are transverse waves and do not need a **medium** (material) through which to travel.

## Describing waves

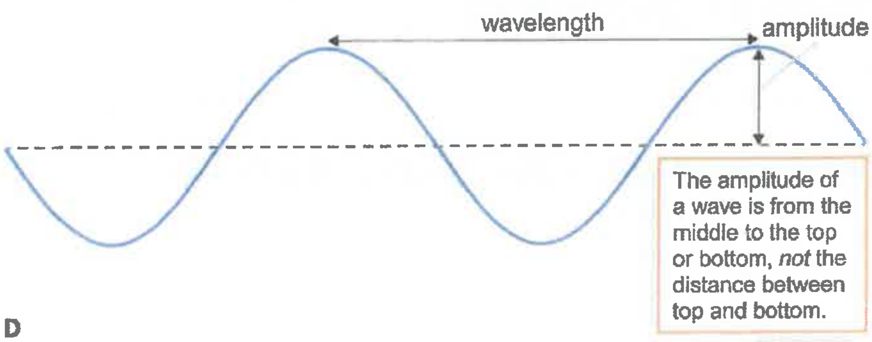
Wave **frequency** is the number of waves passing a point each second. It is measured in **hertz (Hz)**. A frequency of 1 hertz means 1 wave passing per second. For sound, the wave frequency determines the pitch (how high or low it sounds) and for light the frequency determines the colour.

The **period** is the length of time it takes one wave to pass a given point.

The **wavelength** of a wave is the distance from a point on one wave to a point in the same position on the next wave, measured in metres.

The **amplitude** of a wave is the maximum distance of a point on the wave away from its rest position, measured in metres. The greater the amplitude of a sound wave, the louder the sound.

The **velocity** of a wave is the speed of the wave in the direction it is travelling. Waves travel at different speeds in different materials.




**D**

Changes in the frequency, wavelength or amplitude of a wave can be used to transfer information from one place to another. For example, when you listen to FM radio, the music is sent by variations in the frequency of the radio waves.

**5** The tops of sea waves pass a stick twice every second.

**a** What is the frequency?

**b** What is the period?

**6** Write down two things that waves transfer and give an example of each.

### Exam-style question

Compare and contrast the way particles move in a sound wave and in a wave on the surface of water. *(4 marks)*

**3** List two types of wave that are:

**a** transverse waves

**b** longitudinal waves.

### Did you know?

The Sun has 'sunquakes'. Huge explosions of gas, called solar flares, cause waves to spread through the Sun in a similar way to Earth movements causing earthquakes.

**4** Suggest how we see light change when the amplitude of light waves varies.

### Checkpoint

How confidently can you answer the Progression questions?

#### Strengthen

**S1** Draw a transverse wave and label the amplitude and wavelength.

**S2** Describe the similarities and differences between longitudinal and transverse waves.

#### Extend

**E1** Write glossary entries for the different terms used to describe waves, including examples of different types of wave.

**E2** Explain the differences between waves on the surface of water and sound waves, in terms of what they transfer and the characteristics of the waves.

# SP4b Wave speeds

Specification reference: P4.6; P4.7

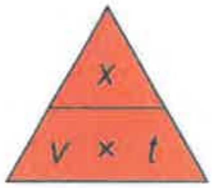
## Progression questions

- How can we calculate the speed (or velocity) of a wave?
- How can we measure the speed of sound in air?
- How can we measure the speed of waves on water?

**A** The sound waves from this volcano plume took time to reach the photographer. This time can be used to calculate how far away the lightning was.

The speed of a wave can be calculated from the distance it travels in a certain time. This is the same equation we use for calculating the speed of moving objects.

$$\text{speed (m/s)} = \frac{\text{distance (m)}}{\text{time (s)}}$$




**B** You can rearrange the equation for speed using this triangle. *v* stands for speed and *x* stands for distance.

**1** Calculate the speed of light waves which travel 900 000 000 m in 3 s.

**2** You hear thunder 5 s after you see lightning.

**a** Sound travels at 330 m/s in air. How far away was the lightning strike?

**b** Explain what assumption you made in your answer.

## Worked example W1

A surfer travels 52 m on the front of a wave in 8 s. Calculate the wave speed.

$$\text{wave speed} = \frac{\text{distance}}{\text{time}}$$

$$\text{wave speed} = \frac{52\text{ m}}{8\text{ s}}$$

$$= 6.5\text{ m/s}$$

## Did you know?

Waves on the surface of water get slower as the water gets shallower. This is what causes waves to break as they reach the shore.

**C**

The wave speed is linked to the wave frequency and wavelength by this equation.

wave speed (m/s) = frequency (Hz) × wavelength (m)

## Worked example W2

Some waves have a wavelength of 13 m and a frequency of 0.5 Hz. Calculate their speed.

$v = f \times \lambda$

$= 0.5\,\text{Hz} \times 13\,\text{m}$

$= 6.5\,\text{m/s}$

**3** Calculate the speed of sound waves that have a wavelength of 2 m and a frequency of 170 Hz.

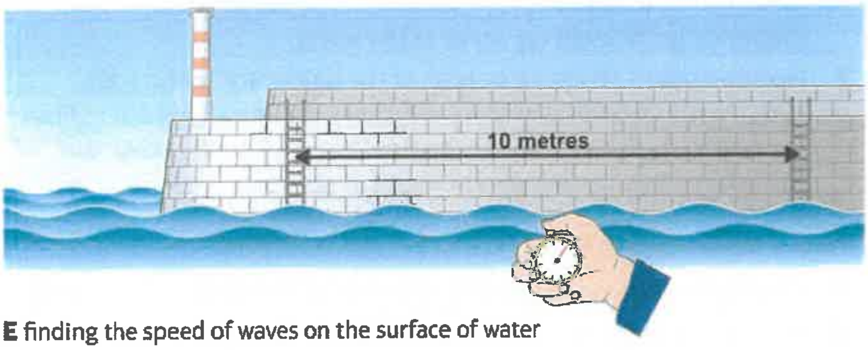
**4** Calculate the wavelength of seismic waves that travel at 5000 m/s and have a frequency of 100 Hz.

The speed of a wave depends on the medium through which it is travelling. Light always travels at 300 000 000 m/s in a vacuum but it travels more slowly in glass or water. When light goes from air into water its wavelength also reduces.

## Measuring the speed of waves

You can find the speed of sound by measuring the time it takes for a sound to travel a certain distance. For example, if you stand in front of a large wall you can measure the time it takes for an echo of a loud sound to reach you. The speed can be calculated using the speed, time, distance equation.

One way of measuring the speed of waves on water is to measure the time it takes for a wave to travel between two fixed points such as buoys. The speed can be calculated from the time and the distance between the points.

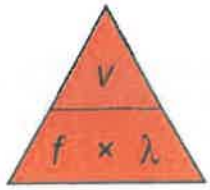



**E** finding the speed of waves on the surface of water

**6** Look at diagram E. It takes 7 s for a wave to move from one ladder to the other. Calculate the speed of the wave.

## Exam-style question

Humans can hear sounds with a wavelength of 16 m. The speed of sound in air is 330 m/s. Calculate the frequency of these sounds. *(3 marks)*




**D** You can rearrange the equation for wave speed using this triangle. *v* stands for speed and *f* stands for frequency. *λ* is the Greek letter lambda and represents wavelength.

**5** When light travels from air into water, its frequency does not change. Explain why its wavelength decreases.

## Checkpoint

How confidently can you answer the Progression questions?

### Strengthen

**S1** An underwater sound wave travels 2000 m in 1.3 s. Calculate its speed.

**S2** The frequency of the sound wave in **S1** is 3000 Hz. Calculate the wavelength of the sound wave.

### Extend

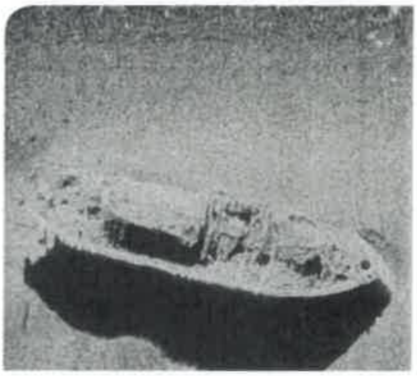
**E1** You are asked to find the speed of ripples on water using the equation linking speed, frequency and wavelength. Describe how to take the measurements you need and how you would work out the speed.

# SP4b Core practical – Investigating waves

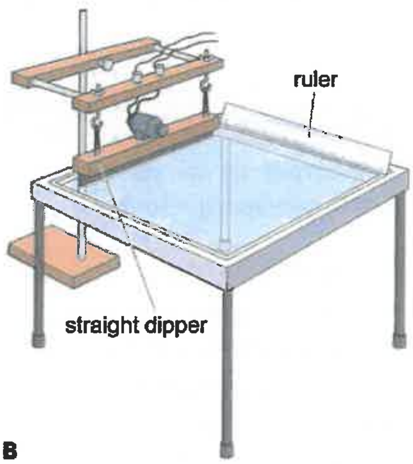
Specification reference: P4.17

## Aim

Investigate the suitability of equipment to measure the speed, frequency and wavelength of a wave in a solid and a fluid.



**A** This photo shows a detailed image of the USS *Monitor* made using frequency sonar. The USS *Monitor* was an iron-hulled steamship that sank in 1862.




**B**

Light waves do not travel very far through sea water before being absorbed by the water or reflected by tiny particles in the water. This makes it impossible to take pictures of things that are deep down on the sea bed. Scientists and explorers use sonar equipment to send sound waves into the water and detect the echoes. The depth can be worked out from the speed of sound in the water and the time it takes for the echo to return.

## Your task

You are going to use different pieces of equipment to measure the speed and wavelength of waves on the surface of water, and the speed and frequency of sound waves in solids.

## Method

### Measuring waves on water

**A** Set up a ripple tank with a straight dipper near one side of the tank. Fasten a ruler to one of the adjacent sides so you can see its markings above the water level.

**B** Vary the voltage to the motor until you get waves with a wavelength about half as long as the ripple tank (so you can always see two waves).

**C** Count how many waves are formed in 10 seconds and write it down.

**D** Look at the waves against the ruler. Use the markings on the ruler to estimate the wavelength of the waves. Use the wavelength and frequency to calculate the speed of the waves.

**E** Mark two points on the same edge of the ripple tank as the ruler. Measure the distance between your points. Use the stopwatch to find out how long it takes a wave to go from one mark to the other. Use this information to calculate the speed of the waves.

### Measuring waves in solids

**F** Suspend a metal rod horizontally using clamp stands and rubber bands.

**G** Hit one end of the rod with a hammer. Hold a smartphone with a frequency app near the rod and note down the peak frequency.

**H** Measure the length of the rod and write it down. The wavelength will be twice the length of the rod.

**I** Use the frequency and wavelength to calculate the speed of sound in the rod.

## Exam-style questions

1 A sound wave in air travels 660 metres in two seconds. Calculate the speed of the sound wave. *(2 marks)*

2 A sound wave travelling in water has a frequency of 100 Hz. The speed of sound in water is 1482 m/s. Calculate the wavelength of the wave. *(2 marks)*

3 Describe how to find the frequency of the waves in the ripple tank using the method in step C. *(2 marks)*

4 Luke estimated the wavelength of the waves in the ripple tank using the method described in step D. Emily took a photo of the waves in the ripple tank and estimated the wavelength using the photo.

Explain which method was likely to give the more accurate result. *(2 marks)*

5 Adanna is watching waves on the sea go past two buoys. She knows the buoys are 20 metres apart. Describe how she can find the speed of the waves. *(2 marks)*

6 Liwei measured the frequency and wavelength of waves in a ripple tank and calculated their speed as 0.4 m/s. Using the method in step E, she calculated the speed as 0.2 m/s.

Explain which result is likely to be more accurate. *(2 marks)*

7 The speed of sound in air can be measured by finding the time it takes for a sound to echo from a nearby wall, and measuring the distance to the wall.

Hitting the end of a metal rod with a hammer causes sound waves to travel along the rod. They reflect from the far end of the rod and continue to move up and down the rod until the energy dissipates.

Give a reason why the method used for finding the speed of sound in air cannot be used for finding the speed of sound in a metal. *(2 marks)*

8 Gina used the method described in step G to measure the frequency of sound in an aluminium rod 0.8 metres in length. She recorded a peak frequency of 4000 Hz. Sound inside a metal rod has a wavelength that is twice the length of the rod.

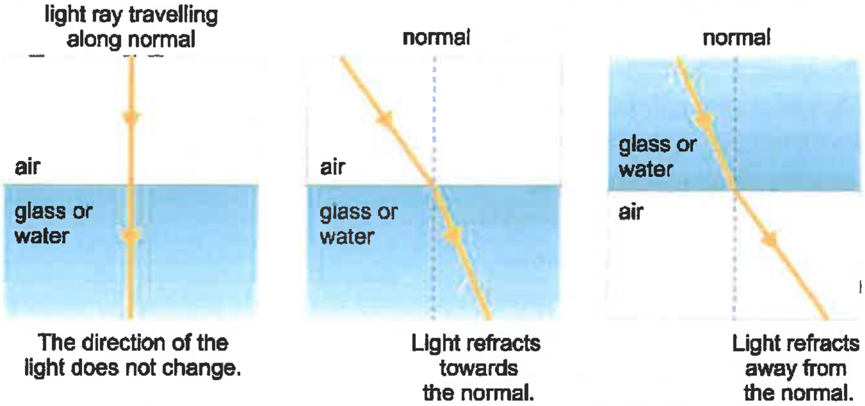
Use Gina's results to calculate the speed of sound in aluminium. *(3 marks)*

# SP4c Refraction

Specification reference: P4.10; H P4.10

## Progression questions

- What happens when waves refract?
- When does refraction occur?
- H How does a change in the speed of a wave affect its direction?




**A** Light is refracted when it goes from one material to another.

Most waves travel outwards from their source in straight lines. However, waves can change direction when they move into a different medium. The change in direction is called **refraction** and happens at the **interface** (boundary) between the two media. A line at right angles to the interface is called the **normal** line. Light travelling along the normal does not change direction when it goes into a different medium.

We see things when light reflected from them reaches our eyes. An object on the bottom of a swimming pool looks closer than it really is because light reflected by it changes direction when it leaves the water.

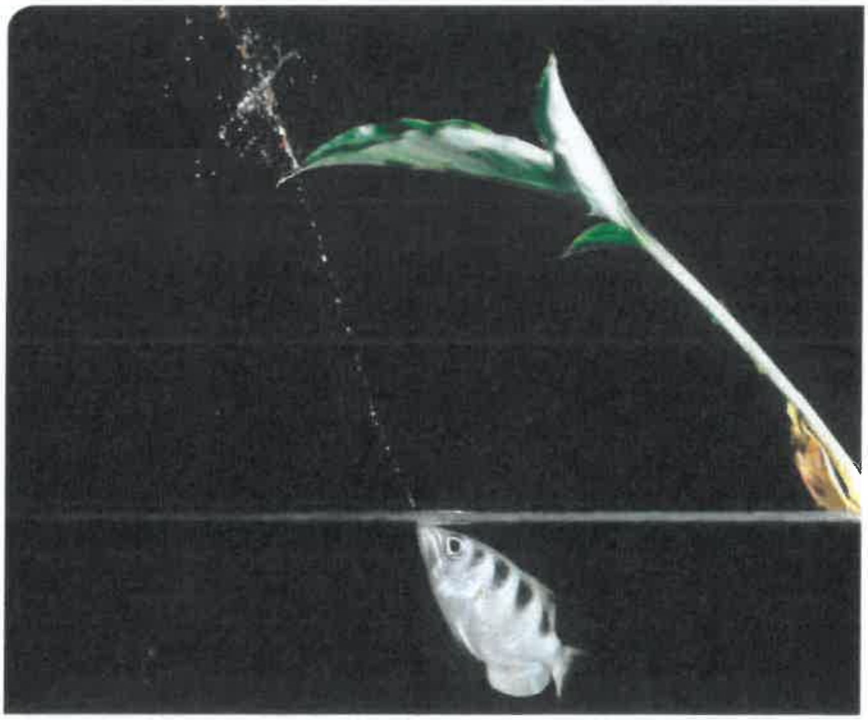
**1** Describe how the direction of a light wave changes when it moves:

**a** from glass into air

**b** from air into glass.

**2** **a** Explain why archerfish (photo B) have to learn to compensate for refraction when aiming at insects.

**b** Draw a diagram to show how light reflected by the insect reaches the fish's eyes.



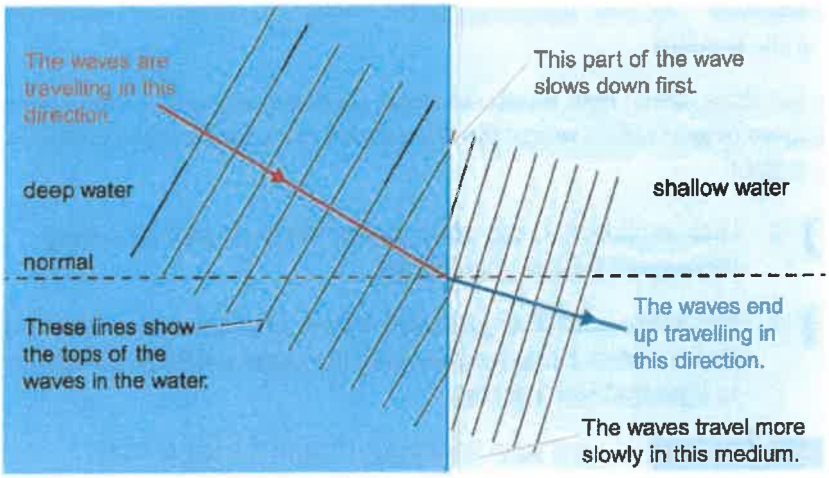
**B** Archerfish knock insects into the water by spitting at them. The fish have to learn to compensate for refraction when aiming at insects.

**H**

Waves can travel through many different media but with different speeds. For example, light travels faster in air than it does in glass or water. As light passes the interface between one medium and another it changes speed. This change in speed causes the direction of the light to change.

The bend depends on how fast the light travels in the two media and the angle of the light hitting the interface. The greater the difference in speed between the two media, the more the light is bent. The light bends towards the normal when it slows down.

We can use waves on water as a model to help us to understand what happens with light waves. The speed of waves on water depends on how deep the water is. Waves moving from deep water into shallow water slow down and change direction (diagram D). Lines on ray diagrams (diagram A) show the direction in which the waves are moving, not the waves themselves.




**D** Water waves change direction when the depth changes.

3 Look at diagram D. Explain what happens to the waves when they move into shallow water.

4 Explain why the waves do not change direction when they are travelling at right angles to the interface.

5 Explain what happens to waves on the surface of water when they cross an interface from shallow water into deeper water.

6 Explain how diagram A shows that light travels more slowly in glass and water than it does in air.

## Exam-style question

Lane markings on the bottom of a swimming pool are straight lines. Explain why they do not usually look straight when you look at them from above the water. *(2 marks)*

## Did you know?

Refraction can also happen when the properties of a material change gradually. A mirage occurs when air near the ground is hotter than air higher up. In this photo, refraction is distorting the path of the light from the sky, making it appear to come from the ground and giving the impression of a puddle of water in the road.

**C**

## Checkpoint

How confidently can you answer the Progression questions?

### Strengthen

**S1** Describe how the direction of a light ray changes as it goes from air into water, and when it goes from water into air. Use the word 'normal' in your answer.

### Extend

**E1** H **A ray of light** shines through a thick piece of glass. Explain why the light ray emerges from the glass travelling in the same direction as originally, but not along the same line. You may use a diagram to help you to explain.

# SP4d Waves crossing boundaries

Specification reference: P4.9P; P4.16P

## Progression questions

- What happens when waves are reflected or refracted?
- What happens when waves are transmitted or absorbed?
- How are changes in velocity, frequency and wavelength related?

**A** The materials in this room reflect and absorb different amounts of light.

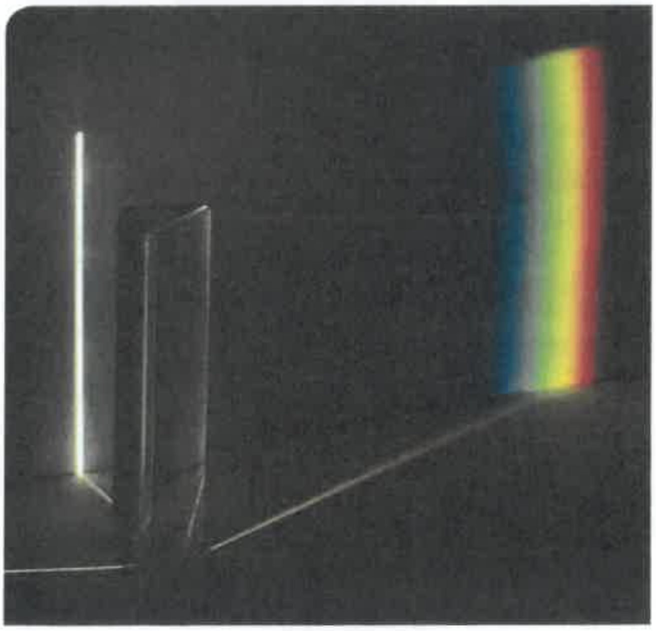
When a wave reaches an interface (boundary) between different materials it can be:

- reflected – the wave 'bounces' off
- refracted – the wave passes into the new material but changes the direction in which it is travelling
- **transmitted** – the wave passes through the material and is not absorbed or reflected
- **absorbed** – the wave disappears as the energy it is carrying is transferred to the material.

We see things when light is reflected from them and enters our eyes. Lighter coloured objects reflect more light than darker ones. Darker objects absorb more light.

**1** Look at photo A. Is the white vase or the dark table absorbing more light? Explain your answer.

**2** The mirror is made of glass with a layer of aluminium on the back. Explain which two processes from the bullet points above happen to light that hits a mirror.



**B** A prism can separate the colours in white light.

Light from light bulbs or from the Sun is called white light, and is made up of a mixture of different frequencies of light. We see these different frequencies as different colours. The different colours in light change speed by different amounts when they travel from air to glass (or from glass to air). This means they are refracted through varying angles, which is why a prism can be used to split up visible light into the colours of the rainbow.

**3** Look at photo B.

**a** How can you tell that the prism is transmitting and refracting light?

**b** How does the photo show that different frequencies are refracted by different amounts?

Sound waves can be affected in the same way as light waves. We hear echoes when sound is reflected by a hard surface. Some materials absorb sound well and some transmit it well. Sound is also refracted when it goes into different materials but this is much harder to observe.

**C** An anechoic chamber is designed to remove all echoes. Anechoic chambers are used to test loudspeakers and other audio equipment.

**4** Look at photo C above. Suggest how well the material of the walls reflects and absorbs sound waves. Explain your answer.

Sound waves travel at different speeds in different materials. Wave velocity is equal to the frequency multiplied by the wavelength, so if the velocity changes, either the frequency or wavelength (or both) must also change. When we hear sounds at different pitches, our ears are detecting the different frequencies of sound (not the wavelengths). A sound has the same pitch if it reaches us through air or through a solid, so when a sound wave enters a different material it is the wavelength and velocity that change, not the frequency.

**5** Sound travels at approximately 330 m/s in air. A sound wave has a frequency of 10 kHz.

**a** Calculate its wavelength.

**b** What will the wavelength be if the sound wave passes into water where the speed is 1500 m/s?

## Exam-style question

Compare and contrast the reflection and refraction of waves at a boundary. *(2 marks)*

## Did you know?

Before radar was invented, acoustic mirrors like this were used to help observers listen for enemy aircraft approaching. They helped to focus the sound waves.

**D** an acoustic mirror

## Checkpoint

How confidently can you answer the Progression questions?

### Strengthen

**S1** Compare and contrast a pair of prescription glasses (to help you to see more clearly) with a pair of sunglasses, using the terms in the bullet points near the top of the previous page.

### Extend

**E1** Sound travels at approximately 4170 m/s in brick. Describe what happens when a sound wave reaches a brick wall and some of it forms an echo. Use the three Progression questions to structure your answer.

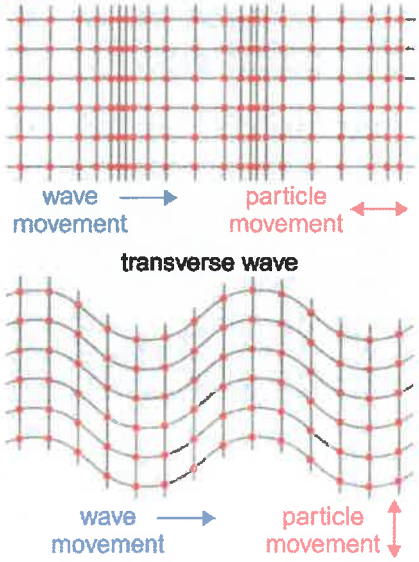
# SP4e Ears and hearing

Specification reference: H P4.12P

## Progression questions

- H How do our ears work?
- H How are sound waves converted to waves in solids?
- H How does the frequency affect the energy transferred to a solid?

H




**A** longitudinal and transverse waves in a solid

## Reflecting and transmitting sound

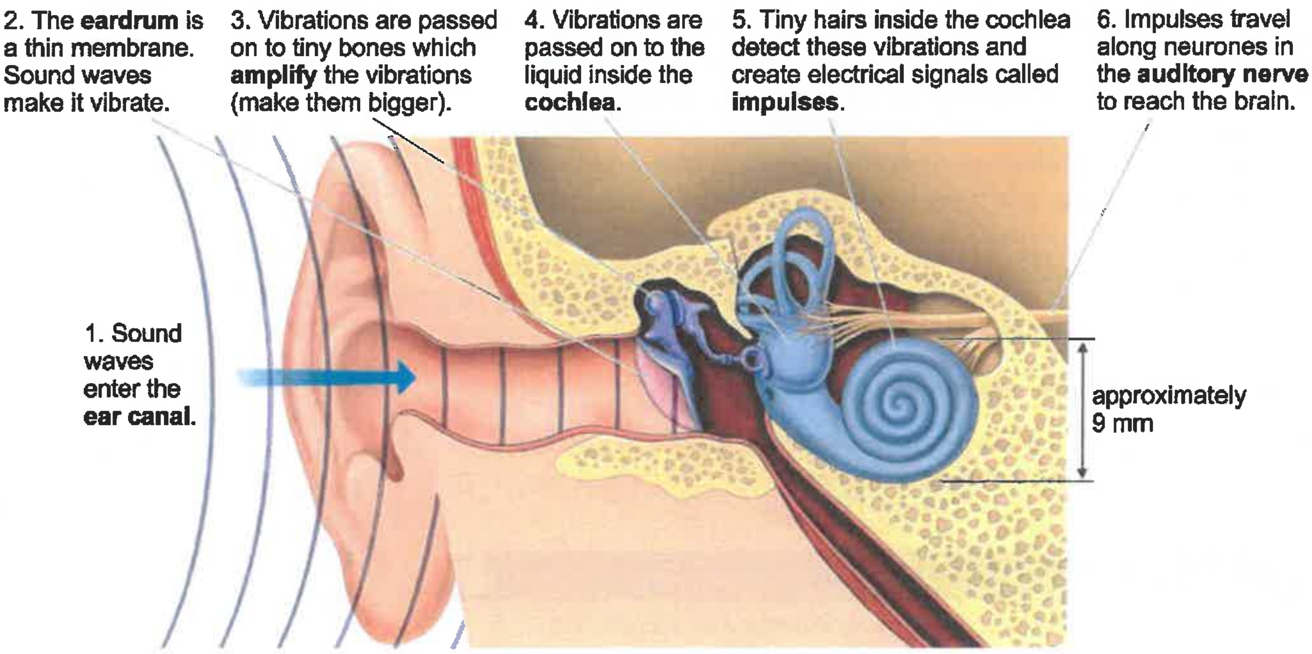
Sound waves are longitudinal waves. Particles in a gas or liquid vibrate backwards and forwards as a sound wave passes. When the sound wave reaches a solid, some of the energy it is transferring is reflected and some is transmitted through the solid or absorbed by it.

A sound wave causes changes in pressure on the surface of a solid. This causes particles in the solid to vibrate and so the disturbance is passed from the air to the solid. The vibrations in the solid can be passed on both as longitudinal waves and transverse waves.

The shape and properties of a solid (such as density and stiffness) determine how vibrations of different frequencies will affect it.

## Human ears

We detect sound waves using our ears. The part of the ear on the outside of our heads helps to channel sound waves into our heads. The vibrations caused by the sound waves are passed on through various parts of the ear until they are detected and converted to electrical impulses that travel to the brain.




**B** the internal structure of a human ear

H

1 List the parts of the ear in the order in which vibrations affect them.

2 Which part of the ear converts vibrations into nerve impulses?

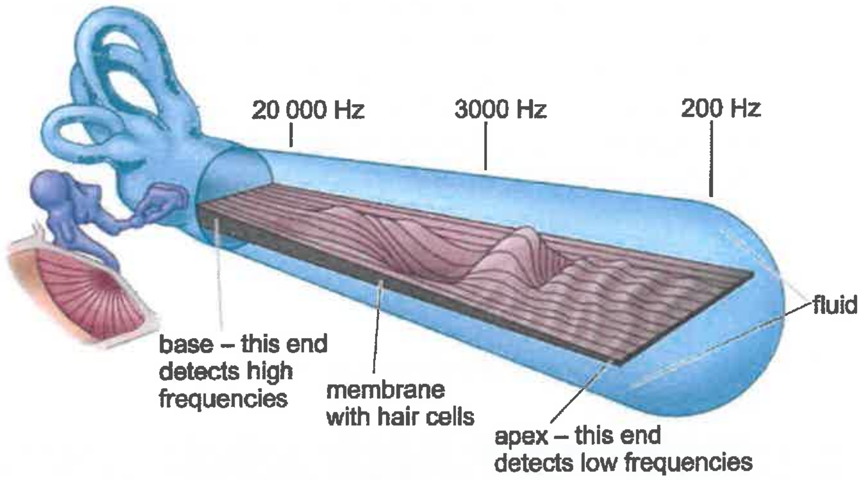
3 In which parts of the ear are the vibrations occurring in a:

**a** solid **b** liquid **c** gas?

## How the cochlea works

The cochlea is a coiled tube containing a liquid. It can detect the different frequencies of sound reaching the ear. Human ears can detect sounds from 20 Hz to 20 000 Hz.

Diagram D shows what the coiled tube of the cochlea would look like if it were unwound. The membrane in the middle of the tube is thicker and stiffer at the base and thinner at the apex. The part of the membrane that vibrates depends on the frequency of the sound waves in the liquid inside the cochlea, as different thicknesses of the membrane vibrate best at different frequencies. There are thousands of hair cells along the membrane, which detect its vibrations. Each hair cell is connected to a **neurone** that sends impulses to the brain. The brain interprets signals from different neurones as different pitches of sound.




**D** the membrane in an unrolled human cochlea

5 Look at diagram D.

**a** Does the thin or thick part of the membrane in the cochlea detect high frequencies?

**b** Why is it important that different parts of the membrane in the cochlea have different stiffnesses?

### Exam-style question

Describe how sound waves in a fluid are converted to vibrations in a solid. *(2 marks)*

### Did you know?

Our bones can conduct vibrations to our cochleas. Bone conduction headphones like these allow joggers and cyclists to listen to music without blocking sounds from things around them.

**C**

4 Describe the functions of the following parts of the cochlea.

**a** fluid

**b** membrane

**c** hair cells

### Checkpoint

How confidently can you answer the Progression questions?

### Strengthen

**S1** Draw a flow chart to describe how we hear sounds. Include how the vibrations are passed on inside the ear, and how the sounds are detected and converted to nerve impulses.

### Extend

**E1** Like all birds, pigeons have straight cochleas. They have a hearing range of 200–7500 Hz. Suggest ways in which the structure of the pigeon cochlea is different to that of humans.

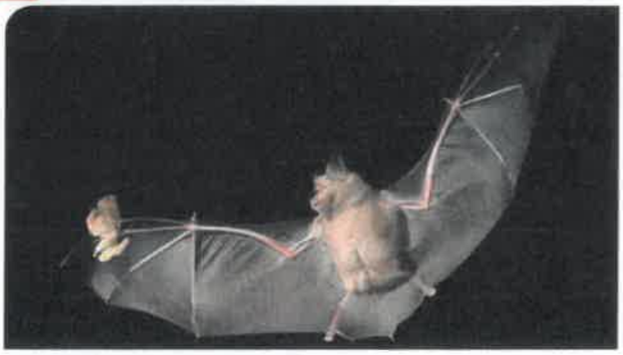
# SP4f Ultrasound

Specification reference: H P4.8P; H P4.13P; H P4.15P

## Progression questions

- H What is ultrasound?
- H How is ultrasound used in sonar systems?
- H How is ultrasound used to look inside our bodies?

H

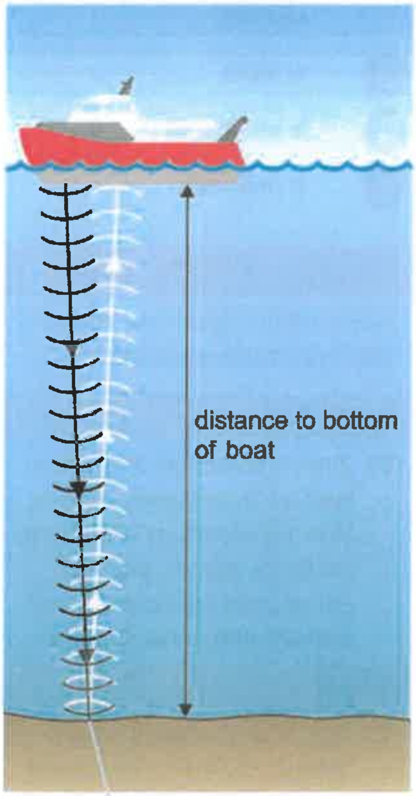


**A** Bats use echolocation to catch insects.

Humans can detect sound waves up to 20 000 Hz (or 20 kHz). Sounds made by waves with higher frequencies than this are called **ultrasound**. Some animals, such as mice, use ultrasound to communicate with each other. Other animals, such as dolphins and bats, can detect objects around them using ultrasound waves. The ultrasound waves they make are reflected by things around them and the animals listen for the echoes.

1 What is ultrasound?

2 Why do biologists need to use special equipment to detect the noises that bats make?




**B** Sonar equipment can map the shape of the sea bed.

**Sonar** equipment carried on ships or submarines uses a similar method to find the depth of the sea or to detect fish. A loudspeaker on the ship emits a pulse of ultrasound. This spreads out through the water and some of it is reflected by the sea bed. A special microphone on the ship detects the echo, and the sonar equipment measures the time between the sound being sent out and the echo returning. The distance travelled by the sound wave can be worked out using this equation.

$$\underset{\text{(metre, m)}}{\text{distance}} = \underset{\text{(metre/second, m/s)}}{\text{speed}} \times \underset{\text{(second, s)}}{\text{time}}$$

3 Why is ultrasound used for investigating the sea floor rather than light?

## Worked example

The speed of sound in sea water is 1500 m/s. The sonar equipment on a boat receives an echo 0.01 s after the ultrasound pulse was sent out. Calculate the depth of the water.

distance = speed × time = 1500 m/s × 0.01 s

= 15 m

The sound has travelled 15 m down to the sea bed and back up again, so the depth of the water is half of this distance.

depth = $\frac{15}{2}$ m

= 7.5 m

H **4** A ship detects a sonar pulse 3 seconds after it was emitted. The speed of sound in sea water is 1500 m/s.

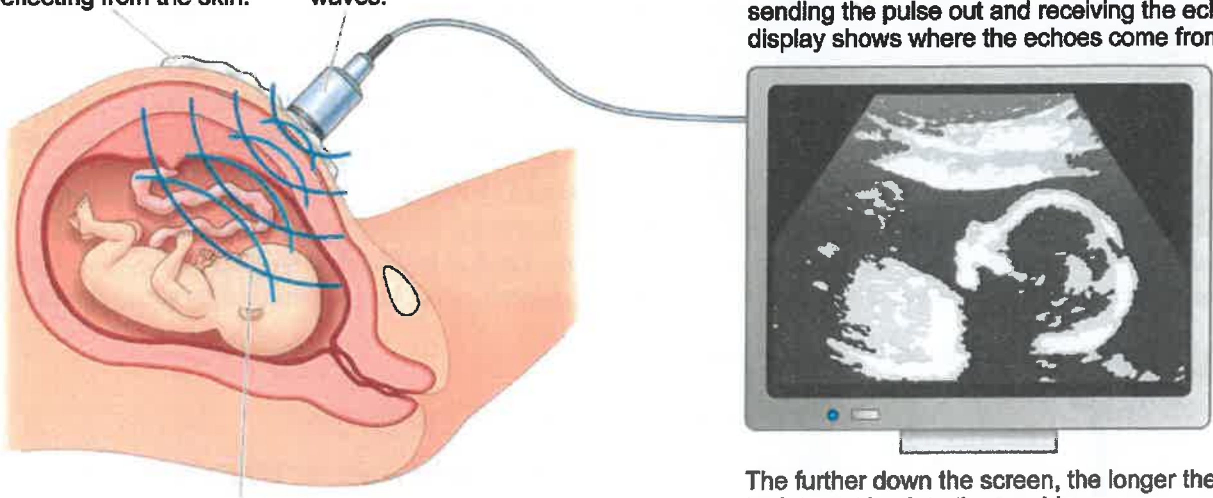
7th **a** How far has the sound travelled?

7th **b** How deep is the water?

**C** The US Navy uses dolphins to find mines, including ones buried in sand. This dolphin is carrying a marker that it will place on a mine it has found.

## Ultrasound scans

Ultrasound can also be used to make images of things inside the body. One common use is to make detailed images of unborn babies so that doctors can monitor how well the fetus is developing.




**D** When an **ultrasound scan** is made, some of the ultrasound waves are reflected each time the waves pass into a different medium.

### Did you know?

Ultrasound can be used to clean things – even your teeth! Most ultrasonic cleaners work by placing delicate items in a solvent. The pressure caused by the ultrasound waves makes millions of tiny bubbles. The forces produced when these bubbles collapse knocks dirt off the item being cleaned.

6th **5** Suggest why ultrasound is used in medical scans rather than visible light.

### Exam-style question

Dolphins are used by some navies to find mines. Explain why dolphins are better than human divers at finding mines. *(2 marks)*

### Checkpoint

How confidently can you answer the Progression questions?

**Strengthen**

**S1** Design a labelled diagram for the manufacturers of 'FishFinder' sonar systems to explain how sonar works and how it can be used to detect fish. Include an example calculation on your diagram.

**Extend**

**E1** Explain how an ultrasound scanner works.

# SP4g Infrasound

Specification reference: H P4.14P; H P4.15P

## Progression questions

- H What is infrasound?
- H How does infrasound travel through the Earth?
- H How can infrasound tell us about the inside of the Earth?

H

Sounds with a frequency less than 20 Hz are too low for humans to hear. These sounds are called **infrasounds**. Infrasound waves travel further than higher frequency sound waves before they become too faint to detect. Animals such as elephants can hear infrasounds.

**1 A vibration has a frequency of 200 Hz. Is it an infrasound? Explain your answer.**

Natural events such as volcanic eruptions and earthquakes create infrasound waves as well as sounds that we can hear.

The vibrations caused by earthquakes are called **seismic waves.** The energy released by an earthquake can travel through the Earth as longitudinal **P waves** and as transverse **S waves**. Seismic waves can be detected by **seismometers**.

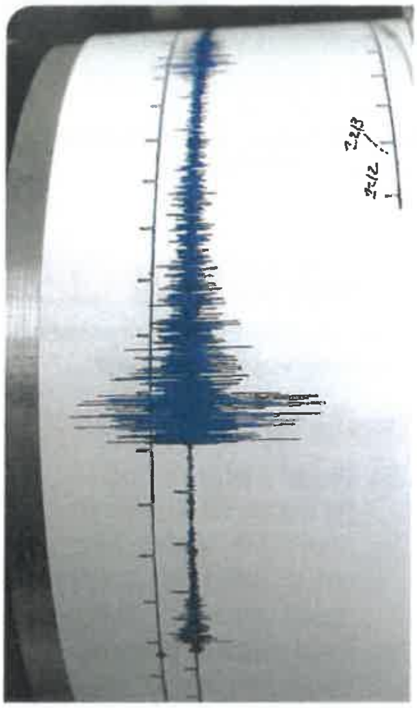
**A** The vibrations of seismic waves can make wet soil turn into a liquid. Buildings can just sink into the ground.

**2 What is:**

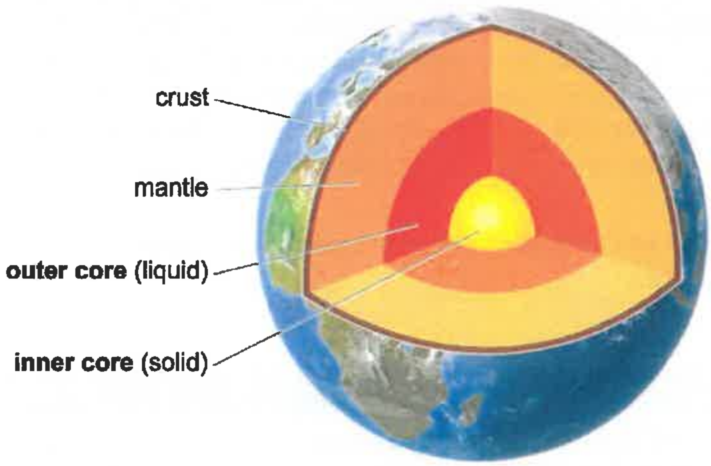
**a a seismic wave** **b a seismometer?**

**3 Explain whether P waves or S waves are infrasound waves.**

Longitudinal waves can be transmitted through solids, liquids and gases. However, transverse waves that need a medium to travel through can only be transmitted by solids. The waves produced by an earthquake can be detected by seismometers all over the world.

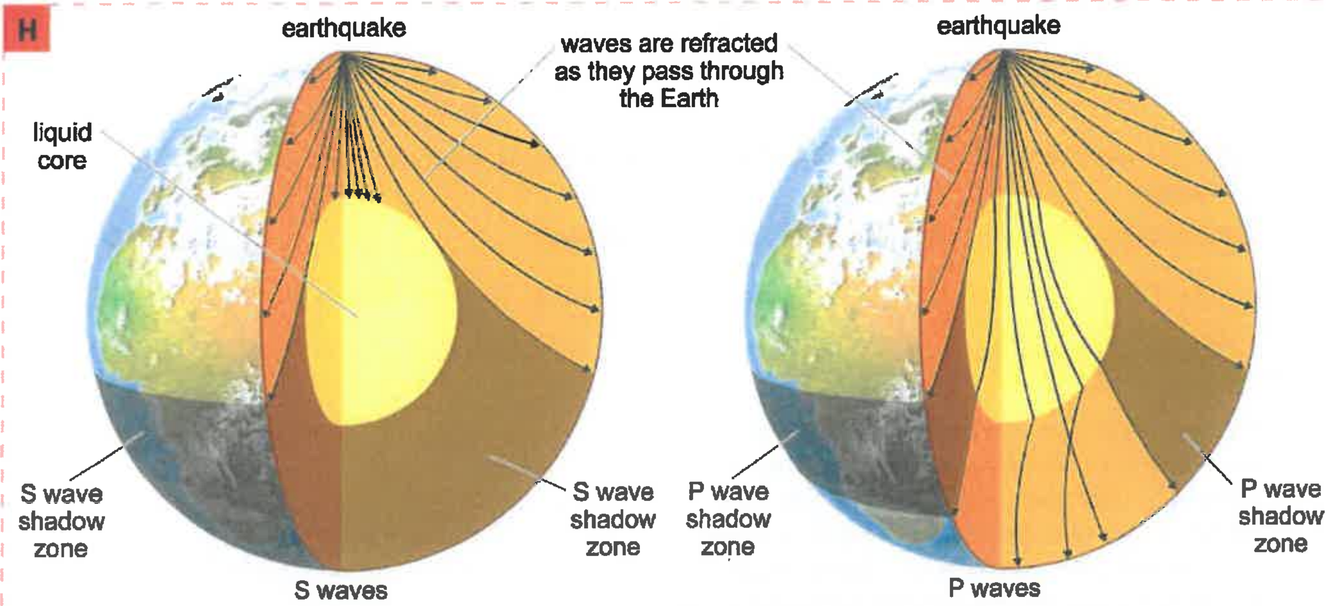


**B** The vibrations detected by seismometers are recorded digitally. In the past, paper drums like this were used to record seismic waves.




**C** Information from seismic waves has been used to develop this model of the Earth.

H




**D** P waves and S waves travel through the Earth in different ways. The same patterns are produced wherever the earthquake occurs.

Scientists use information about the time the waves arrive in different places and the speed of the waves in different types of rocks to model the paths the waves have taken through the Earth.

The places where the waves are detected depend on where an earthquake occurs, but there is always a large area of the Earth on the opposite side to the earthquake were no S waves are detected. This is called the S wave **shadow zone** and occurs because part of the interior of the Earth is liquid. There is also a band around the Earth called the P wave shadow zone.

After the model shown in diagram D was developed, it was discovered that there were a few, weak P waves arriving in the P wave shadow zone. These could only occur if waves in the liquid core had been reflected by something solid. The current model includes a liquid outer core and a solid inner core.

## Did you know?

The solid inner core was first suggested by the Danish scientist Inge Lehmann (1888–1993) in 1936, based on P wave arrivals. Many scientists accepted her model but it was not confirmed until 1971 when computer modelling was used to check her interpretation.

6th **4** Why does the S wave shadow zone suggest that part of the Earth must be liquid?

**5** Seismic waves follow curved paths through the Earth. What does this tell you about:

6th **a** the speed of the waves within the Earth

7th **b** the properties of the rocks in the Earth?

7th **6** Look at diagram D. Explain why there is a P wave shadow zone.

## Exam-style question

**a** State the meaning of infrasound. *(1 mark)*

**b** Give one use for it. *(1 mark)*

## Checkpoint

How confidently can you answer the Progression questions?

### Strengthen

**S1** Explain why infrasound is useful for studying the Earth's core.

### Extend

**E1** Explain how the P wave and S wave shadow zones show the nature of the Earth's core.

# Waves

Waves on water in a ripple tank are often used as a model to help students to understand sound waves and light waves.

Compare and contrast waves on water, sound waves and light waves. **(6 marks)**

## Student answer

*All waves move energy around* [1]. *We get big water waves on the sea and they can damage things in storms* [2]. *Light waves don't have particals, but waves on water and sound waves both have moving particals that make the waves* [3]. *Light can go through vacumes. We can use light waves and sound waves to send information, but we don't use waves on water for sending information* [4].

[1] This is one similarity between all the types of waves mentioned.

[2] The statement about waves on the sea does not add any further scientific information.

[3] This is a difference between light waves and the other two types of waves.

[4] This is a difference between waves on water and the other two types of waves.

## Verdict

This is an acceptable answer. The student has given one similarity between all the waves and pointed out some differences.

The answer could be improved by including more comparisons, such as whether the waves are transverse or longitudinal, or commenting on how fast they travel. A really good answer would also link facts together with scientific ideas – for example, by making it clear that light waves can travel through a vacuum *because* these waves do not need particles to pass them on.

The answer could also be improved by correcting the spelling of the scientific words.

### Exam tip

When a question asks you to 'compare and contrast', you need to mention at least one similarity *and* at least one difference between *all* the things mentioned in the question.

# Double BTEC Science Tasks

## Biology

# Transition from GCSE to BTEC Science

Moving from GCSE Science to A Level can be a daunting leap. You'll be expected to remember a lot more facts, equations, and definitions, and you will need to learn new maths skills and develop confidence in applying what you already know to unfamiliar situations.

## Practical science key terms

You need to be confident about the definitions of terms that describe measurements and results in BTEC Science

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many answers as you can. Check and repeat.

| | |
|---|---|
| When is a measurement valid? | when it measures what it is supposed to be measuring |
| When is a result accurate? | when it is close to the true value |
| What are precise results? | when repeat measurements are consistent/agree closely with each other |
| What is repeatability? | how precise repeated measurements are when they are taken by the *same* person, using the *same* equipment, under the *same* conditions |
| What is reproducibility? | how precise repeated measurements are when they are taken by *different* people, using *different* equipment |
| What is the uncertainty of a measurement? | the interval within which the true value is expected to lie |
| Define measurement error | the difference between a measured value and the true value |
| What type of error is caused by results varying around the true value in an unpredictable way? | random error |
| What is a systematic error? | a consistent difference between the measured values and true values |
| What does zero error mean? | a measuring instrument gives a false reading when the true value should be zero |
| Which variable is changed or selected by the investigator? | independent variable |
| What is a dependent variable? | a variable that is measured every time the independent variable is changed |
| Define a fair test | a test in which only the independent variable is allowed to affect the dependent variable |
| What are control variables? | variables that should be kept constant to avoid them affecting the dependent variable |

## Basic components of living systems

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many answers as you can. Check and repeat.

| | |
|---|---|
| What is the formula to calculate magnification? | $\text{magnification} = \dfrac{\text{size of image}}{\text{size of object}}$ actual |
| Why are cells stained before being viewed with a light microscope? | staining increases contrast between different cell components, makes them visible, and allows them to be identified |
| What is an eyepiece graticule? | a glass disc that fits on top of the eyepiece lens that is marked with a fine scale from 1 to 100 |
| What is a stage micrometer? | a microscope slide with a very accurate scale in micrometers (μ) engraved on it |
| What is a scientific drawing? | a labelled line drawing that is used to highlight particular features and does not include unnecessary detail or shading, it should always have a title and state the magnification |
| What is magnification? | how many times larger an image is than the actual size of the object being viewed |
| What is resolution? | the ability to see individual objects as separate entities |
| What is the function of the nucleus? | controls the metabolic activities of the cell as it contains genetic information in the form of DNA |
| What is the nucleolus? | area within the nucleus that is responsible for producing ribosomes |
| What is the function of mitochondria? | site of production of ATP in the final stages of cellular respiration |
| What are vesicles? | membranous sacs that are used to transport materials in the cell |
| What are lysosomes? | specialised forms of vesicles with hydrolytic enzymes that break down waste material in cells |
| What is the role of the cytoskeleton? | controls cell movement, movement of organelles within the cell, and provides mechanical strength to the cell |
| Name the three types of cytoskeletal filaments | microfilaments, microtubules, and intermediate fibres |
| Give two types of extension that protrude from some cells | flagella (whip-like protrusions) and cilia (tail-like protrusions) |
| What is the endoplasmic reticulum (ER)? | a network of membranes enclosing flattened sacs called cisternae |
| What are the functions of the two types of ER? | smooth ER – lipid and carbohydrate synthesis, and storage<br>rough ER – synthesis and transport of proteins |
| What is the function of the Golgi apparatus? | plays a part in modifying proteins and packaging them into vesicles |

# Suggested activities

## Maths skills

### Working with formulae

It is often necessary to use a mathematical formula to calculate quantities. You may be tested on your ability to substitute numbers into formulae or to rearrange formulae to find specific values.

### 3.1 Substituting into formulae

Think about the data you are given in the question. Write down the equation and then think about how to get the data to substitute into the equation. Look at this worked example.

A cheek cell has a 0.06 mm diameter. Under a microscope it has a diameter 12 mm. What is the magnification?

$$\text{magnification} = \text{image size (mm)} \div \text{object size (mm)} \quad \text{or} \quad M = \frac{I}{O}$$

Substitute the values and calculate the answer:

$$M = 12\text{ mm}/0.06\text{ mm} = 12/0.06 = 200$$

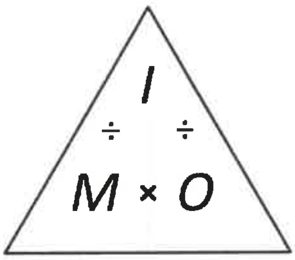
Answer: magnification = ×200 (magnification has no units)

Sometimes an equation is more complicated and the steps need to be carried out in a certain order to succeed. A general principle applies here, usually known by the mnemonic BIDMAS. This stands for **B**rackets, **I**ndices (functions such as squaring or powers), **D**ivision, **M**ultiplication, **A**ddition, **S**ubtraction.

### 3.2 Rearranging formulae

Sometimes you will need to rearrange an equation to calculate the answer to a question. For example, the relationship between magnification, image size, and actual size of specimens in micrographs usually uses the equation $M = \frac{I}{O}$, where $M$ is magnification, $I$ is size of the image, and $O$ = actual size of the object.

You can use the algebra you have learnt in Maths to rearrange equations, or you can use a triangle like the one shown.




Cover the quantity you want to find. This leaves you with either a fraction or a multiplication:

$M = I \div O$ $\quad$ $O = I \div M$ $\quad$ $I = M \times O$

## 4 Magnification

To look at small biological specimens you use a microscope to magnify the image that is observed. The microscope was developed in the 17th century. Anton van Leeuwenhoek used a single lens and Robert Hooke used two lenses. The lenses focus light from the specimen onto your retina to produce a magnified virtual image. The magnification at which observations are made depends on the lenses used.

### 4.1 Calculating the magnifying power of lenses

Lenses each have a magnifying power, defined as the number of times the image is larger than the real object. The magnifying power is written on the lens.

To find the magnification of the virtual image that you are observing, multiply the magnification powers of each lens used. For example, if the eyepiece lens is ×10 and the objective lens is ×40 the total magnification of the virtual image is 10 × 40 = 400.

### *Practice questions*

**1** Calculate the magnification of the virtual image produced by the following combinations of lenses:

**a** objective ×10 and eyepiece ×12

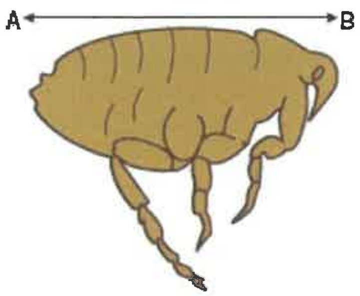
**b** objective ×40 and eyepiece ×15

### 4.2 Calculating the magnification of images

Drawings and photographs of biological specimens should always have a magnification factor stated. This indicates how much larger or smaller the image is compared with the real specimen.

The magnification is calculated by comparing the sizes of the image and the real specimen. Look at this worked example.

The image shows a flea which is 1.3 mm long. To calculate the magnification of the image, measure the image (or the scale bar if given) on the paper (in this example, the body length as indicated by the line A–B).




For this image, the length of the image is 42 mm and the length of the real specimen is 1.3 mm.

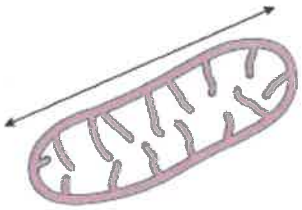
$$\text{magnification} = \frac{\text{length of image}}{\text{length of real specimen}} = 42/1.3 = 32.31$$

The magnification factor should therefore be written as ×32.31

**Remember:** Use the same units. A common error is to mix units when performing these calculations. Begin each time by converting measurements to the same units for both the real specimen and the image.

### *Practice questions*

2 Calculate the magnification factor of a mitochondrion that is 1.5 µm long.



## 4.3 Calculating real dimensions

Magnification factors on images can be used to calculate the actual size of features shown on drawings and photographs of biological specimens. For example, in a photomicrograph of a cell, individual features can be measured if the magnification is stated. Look at this worked example.

The magnification factor for the image of the open stoma is ×5000.

This can be used to find out the actual size of any part of the cell, for example, the length of one guard cell, measured from A to B.

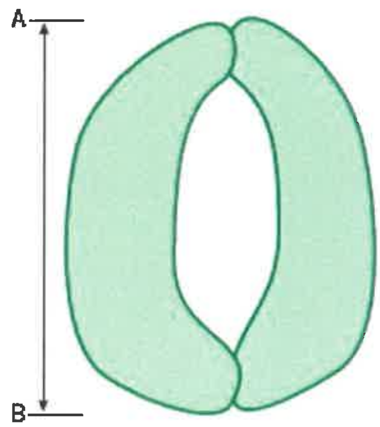
**Step 1:** Measure the length of the guard cell as precisely as possible. In this example the image of the guard cell is 52 mm long.

**Step 2:** Convert this measurement to units appropriate to the image. In this case you should use µm because it is a cell.

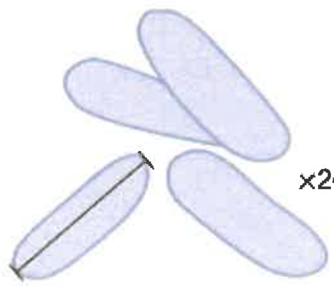
So the magnified image is 52 × 1000 = 52 000 µm

**Step 3:** Rearrange the magnification equation (see Topic 3.2) to get:

real size = size of image/magnification = 52 000/5000 = 10.4 So the real length of the guard cell is 10.4 µm.




3 Use the magnification factor to determine the actual size of a bacterial cell.



# Answers to maths skills practice questions

## 4 Magnification

**1** **a** ×120 **b** ×600

**2** ×26 000 **3** 0.88 μm

# Double BTEC Science Tasks

# Chemistry

Notice that the zeros before the figure are *not* significant – they just show you how large the number is by the position of the decimal point. Here, a 5 follows the last significant digit, so just as with decimals, it must be rounded up.

Any zeros between the other significant figures are significant. For example, 0.003 018 is 0.003 02 to three significant figures.

Sometimes numbers are expressed to a number of decimal places. The decimal point is a place holder and the number of digits afterwards is the number of decimal places.

For example, the mathematical number pi is 3 to zero decimal places, 3.1 to one decimal place, 3.14 to two decimal places, and 3.142 to three decimal places.

### *Practice questions*

**3** Give the following values in the stated number of significant figures (s.f.).

**a** 36.937 (3 s.f.) **b** 258 (2 s.f.) **c** 0.043 19 (2 s.f.) **d** 7 999 032 (1 s.f.) **4** Use the equation: number of molecules = number of moles × 6.02 × $10^{23}$ molecules per mole to calculate the number of molecules in 0.5 moles of oxygen. Write your answer in standard form to 3 s.f.

**5** Give the following values in the stated number of decimal places (d.p.). **a** 4.763 (1 d.p.) **b** 0.543 (2 d.p.) **c** 1.005 (2 d.p.) **d** 1.9996 (3 d.p.)

## 1.3 Converting units

Units are defined so that, for example, every scientist who measures a mass in kilograms uses the same size for the kilogram and gets the same value for the mass. Scientific measurement depends on standard units – most are *Système International* (SI) units.

If you convert between units and round numbers properly it allows quoted measurements to be understood within the scale of the observations.

| Multiplication factor | Prefix | Symbol |
|---|---|---|
| $10^9$ | giga | G |
| $10^6$ | mega | M |
| $10^3$ | kilo | k |
| $10_{-2}$ | centi | c |
| $10^{-3}$ | milli | m |
| $10^{-6}$ | micro | µ |
| $10^{-9}$ | nano | n |

Unit conversions are common. For instance, you could be converting an enthalpy change of 488 889 J $mol^{-1}$ into kJ $mol^{-1}$. A kilo is $10^3$ so you need to divide by this number or move the decimal point three places to the left.

488 889 ÷ $10^3$ kJ $mol^{-1}$ = 488.889 kJ $mol^{-1}$

Converting from mJ $mol^{-1}$ to kJ $mol^{-1}$, you need to go from $10^3$ to $10^{-3}$, or move the decimal point six places to the left.

333 mJ $mol^{-1}$ is 0.000 333 kJ $mol^{-1}$

If you want to convert from 333 mJ $mol^{-1}$ to nJ $mol^{-1}$, you would have to go from $10^{-9}$ to $10^{-3}$, or move the decimal point six places to the right.

333 mJ $mol^{-1}$ is 333 000 000 nJ $mol^{-1}$

### *Practice questions*

**6** Calculate the following unit conversions.

**a** 300 μm to m

**b** 5 MJ to mJ

**c** 10 GW to kW

## 2 Balancing chemical equations

### 2.1 Conservation of mass

When new substances are made during chemical reactions, atoms are not created or destroyed – they just become rearranged in new ways. So, there is always the same number of each type of atom before and after the reaction, and the total mass before the reaction is the same as the total mass after the reaction. This is known as the conservation of mass.

You need to be able to use the principle of conservation of mass to write formulae, and balanced chemical equations and half equations.

### 2.2 Balancing an equation

The equation below shows the correct formulae but it is not balanced.

$H_2 + O_2 \rightarrow H_2O$

While there are two hydrogen atoms on both sides of the equation, there is only one oxygen atom on the right-hand side of the equation against two oxygen atoms on the left-hand side. Therefore, a two must be placed before the $H_2O$.

$H_2 + O_2 \rightarrow 2H_2O$

Now the oxygen atoms are balanced but the hydrogen atoms are no longer balanced. A two must be placed in front of the $H_2$.

$2H_2 + O_2 \rightarrow 2H_2O$

The number of hydrogen and oxygen atoms is the same on both sides, so the equation is balanced.

### *Practice questions*

1 Balance the following equations.

**a** $C + O_2 \rightarrow CO$ **b** $N_2 + H_2 \rightarrow NH_3$ **c** $C_2H_4 + O_2 \rightarrow H_2O + CO_2$

### 2.3 Balancing an equation with fractions

To balance the equation below:

$C_2H_6 + O_2 \rightarrow CO_2 + H_2O$

- Place a two before the $CO_2$ to balance the carbon atoms.
- Place a three in front of the $H_2O$ to balance the hydrogen atoms. $C_2H_6 + O_2 \rightarrow 2CO_2 + 3H_2O$

There are now four oxygen atoms in the carbon dioxide molecules plus three oxygen atoms in the water molecules, giving a total of seven oxygen atoms on the product side.

- To balance the equation, place three and a half in front of the $O_2$. $C_2H_6 + 3\frac{1}{2}O_2 \rightarrow 2CO_2 + 3H_2O$
- Finally, multiply the equation by 2 to get whole numbers. $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$

### *Practice questions*

2 Balance the equations below. **a** $C_6H_{14}$ + $O_2 \rightarrow CO_2 + H_2O$ **b** $NH_2CH_2COOH + O_2 \rightarrow CO_2 + H_2O + N_2$

### 2.4 Balancing an equation with brackets

$Ca(OH)_2 + HCl \rightarrow CaCl_2 + H_2O$

Here the brackets around the hydroxide ($OH^-$) group show that the $Ca(OH)_2$ unit contains one calcium atom, two oxygen atoms, and two hydrogen atoms.

To balance the equation, place a two before the HCl and another before the $H_2O$.

$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 + 2H_2O$

### *Practice questions*

3 Balance the equations below.

**a** $Mg(OH)_2 + HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$ **b** $Fe(NO_3)_2 + Na_3PO_4 \rightarrow Fe_3(PO_4)_2 + NaNO_3$

## 3 Rearranging equations and calculating concentrations

### 3.1 Rearranging equations

In chemistry, you sometimes need to rearrange an equation to find the desired values.

For example, you may know the amount of a substance (*n*) and the mass of it you have (*m*), and need to find its molar mass (*M*).

The amount of substance (*n*) is equal to the mass you have (*m*) divided by the molar mass (*M*):

$$n = \frac{m}{M}$$

You need to rearrange the equation to make the molar mass (*M*) the subject.

Multiply both sides by the molar mass (*M*):

$$M \times n = m$$

Then divide both sides by the amount of substance (*n*):

$$m = \frac{m}{N}$$

### *Practice questions*

1 Rearrange the equation $c = \frac{n}{V}$ to make:

**a** *n* the subject of the equation **b** *V* the subject of the equation.

2 Rearrange the equation $PV = nRT$ to make:

**a** *n* the subject of the equation

**b** *T* the subject of the equation.

# Answers to maths skills practice questions

## 1 Core mathematics

1 **a** $1.413 \times 10^3$ °C **b** $1.0 \times 10^{-7}$ m
**c** $1.806 \times 10^{21}$ atoms

2 **a** 0.000 0055 **b** 290 **c** 11150
**d** 0.001 412 **e** 72

3 **a** 36.9 **b** 260 **c** 0.043 **d**
8 000 000

4 Number of molecules = 0.5 moles × $6.022 \times 10^{23} = 3.011 \times 10^{23} = 3.01 \times 10^{23}$

5 **a** 4.8 **b** 0.54 **c** 1.01 **d**
2.000

6 **a** 0.0003 m **b** $5 \times 10^9$ mJ **c** $1 \times 10^7$
kW

## 2 Balancing chemical equations

1 **a** $2C + O_2 \rightarrow 2CO$ **b** $N_2 + 3H_2 \rightarrow 2NH_3$ **c**
$C_2H_4 + 3O_2 \rightarrow 2H_2O + 2CO_2$

2 **a** $C_6H_{14} + 9\frac{1}{2}O_2 \rightarrow 6CO_2 + 7H_2O$ **or** $2C_6H_{14} + 19O_2 \rightarrow 12CO_2 + 14H_2O$ **b** $2NH_2CH_2COOH + 4\frac{1}{2}O_2 \rightarrow 4CO_2 + 5H_2O + N_2$ **or** $4NH_2CH_2COOH + 9O_2 \rightarrow 8CO_2 + 10H_2O + 2N_2$

3 **a** $Mg(OH)_2 + 2HNO_3 \rightarrow Mg(NO_3)_2 + 2H_2O$ **b**
$3Fe(NO_3)_2 + 2Na_3PO_4 \rightarrow Fe_3(PO_4)_2 + 6NaNO_3$

## 3 Rearranging equations and calculating concentrations

1 **a** $n = cv$ **b** $v = \frac{n}{c}$

2 **a** $n = \frac{PV}{RT}$ **b** $T = \frac{PV}{nR}$

0.2

## Atomic structure

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many answers as you can. Check and repeat.

| | |
|---|---|
| What does an atom consist of? | a nucleus containing protons and neutrons, surrounded by electrons |
| What are the relative masses of a proton, neutron, and electron? | 1, 1, and $\frac{1}{1840}$ respectively |
| What are the relative charges of a proton, neutron, and electron? | +1, 0, and -1 respectively |
| How do the number of protons and electrons differ in an atom? | they are the same because atoms have neutral charge |
| What force holds an atomic nucleus together? | strong nuclear force |
| What is the atomic number of an element? | the number of protons in the nucleus of a single atom of an element |
| What is the mass number of an element? | number of protons + number of neutrons |
| What is an isotope? | an atom with the same number of protons but different number of neutrons |
| What is an ion? | an atom, or group of atoms, with a charge |
| What is the function of a mass spectrometer? | it accurately determines the mass and abundance of separate atoms or molecules, to help us identify them |
| What is a mass spectrum? | the output from a mass spectrometer that shows the different isotopes that make up an element |
| What is the total number of electrons that each electron shell (main energy level) can contain? | $2n^2$ electrons, where $n$ is the number of the shell |
| How many electrons can the first three electron shells hold each? | 2 electrons (first shell), 8 electrons (second shell), 18 electrons (third shell) |
| What are the first four electron sub-shells (orbitals) called? | s, p, d, and f (in order) |
| How many electrons can each orbital hold? | a maximum of 2 electrons |
| Define the term ionisation energy, and give its unit | the energy it takes to remove a mole of electrons from a mole of atoms in the gaseous state, unit = kJ $mol^{-1}$ |
| What is the equation for relative atomic mass ($A_r$)? | relative atomic mass = $\frac{\text{average mass of 1 atom}}{\frac{1}{12}\text{th}}$ |

| | |
|---|---|
| | mass of 1 atom of $^{12}C$ |
| What is the equation for relative molecular mass ($M_r$)? | relative molecular mass = $\frac{\text{average mass of 1 molecule}}{\frac{1}{12}^{th} \text{ mass of 1 atom of } ^{12}C}$ |

# Maths skills

## 1 Core mathematical skills

A practical chemist must be proficient in standard form, significant figures, decimal places, SI units, and unit conversion.

### 1.1 Standard form

In science, very large and very small numbers are usually written in standard form. Standard form is writing a number in the format A × $10^x$ where A is a number from 1 to 10 and x is the number of places you move the decimal place.

For example, to express a large number such as 50 000 mol $dm^{-3}$ in standard form, A = 5 and x = 4 as there are four numbers after the initial 5.

Therefore, it would be written as $5\times10^4$ mol $dm^{-3}$.

To give a small number such as 0.000 02 $Nm^2$ in standard form, A = 2 and there are five numbers before it so x = −5.

So it is written as $2\times10^{-5}$ $Nm^2$.

### *Practice questions*

1 Change the following values to standard form. **a** boiling point of sodium chloride: 1413 °C **b** largest nanoparticles: 0.0 001×$10^{-3}$ m **c** number of atoms in 1 mol of water: 1806×$10^{21}$

2 Change the following values to ordinary numbers.
**a** $5.5\times10^{-6}$ **b** $2.9\times10^2$ **c** $1.115\times10^4$ **d** $1.412\times10^{-3}$ **e** $7.2\times10^1$

### 1.2 Significant figures and decimal places

In chemistry, you are often asked to express numbers to either three or four significant figures. The word significant means to 'have meaning'. A number that is expressed in significant figures will only have digits that are important to the number's precision.

It is important to record your data and your answers to calculations to a reasonable number of significant figures. Too many and your answer is claiming an accuracy that it does not have, too few and you are not showing the precision and care required in scientific analysis.

For example, 6.9301 becomes 6.93 if written to three significant figures.

Likewise, 0.000 434 56 is 0.000 435 to three significant figures.

# Double BTEC Science Tasks

# Physics

## Foundations of Physics

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many answers as you can. Check and repeat.

| | |
|---|---|
| What is a physical quantity? | a property of an object or of a phenomenon that can be measured |
| What are the S.I. units of mass, length, and time? | kilogram (kg), metre (m), second (s) |
| What base quantities do the S.I. units A, K, and mol represent? | current, temperature, amount of substance |
| List the prefixes, their symbols and their multiplication factors from pico to tera (in order of increasing magnitude) | pico (p) $10^{-12}$, nano (n) $10^{-9}$, micro (μ) $10^{-6}$, milli (m) $10^{-3}$, centi (c) $10^{-2}$, deci (d) $10^{-1}$, kilo (k) $10^{3}$, mega (M) $10^{6}$, giga (G) $10^{9}$, tera (T) $10^{12}$ |
| What is a scalar quantity? | a quantity that has magnitude (size) but *no* direction |
| What is a vector quantity? | a quantity that has magnitude (size) *and* direction |
| What is the difference between distance and displacement? | distance is a scalar quantity<br>displacement is a vector quantity |
| What does the Greek capital letter Δ (delta) mean? | 'change in' |
| What is the equation for average speed in algebraic form? | $v = \frac{\Delta x}{\Delta t}$ |
| What is instantaneous speed? | the speed of an object over a very short period of time |
| What does the gradient of a displacement–time graph tell you? | velocity |
| How can you calculate acceleration and displacement from a velocity–time graph? | acceleration is the gradient<br>displacement is the area under the graph |
| Write the equation for acceleration in algebraic form | $a = \frac{\Delta v}{\Delta t}$ |
| Define *stopping distance* | the total distance travelled from when the driver first sees a reason to stop, to when the vehicle stops |
| Define *thinking distance* | the distance travelled between the moment when you first see a reason to stop to the moment when you use the brake |
| Define *braking distance* | the distance travelled from the time the brake is applied until the vehicle stops |
| What does *free fall* mean? | when an object is accelerating under gravity with no other force acting on it |

## Radiation

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many answers as you can. Check and repeat.

| | |
|---|---|
| List the seven main parts of the electromagnetic spectrum from longest wavelength to shortest | radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays |
| Write the equation for calculating the wavelength of electromagnetic radiation | wavelength (λ) = speed of light ( )*c* / frequency ( )*f* |
| Define a *photon* | a packet of electromagnetic waves |
| What is the speed of light? | $3.00 \times 10^8$ m $s^{-1}$ |

# Maths skills

## 1 Measurements

### 1.1 Base and derived SI units

Units are defined so that, for example, every scientist who measures a mass in kilograms uses the same size for the kilogram and gets the same value for the mass. Scientific measurement depends on standard units – most are *Système International* (SI) units. Every measurement must give the unit to have any meaning. You should know the correct unit for physical quantities.

**Base units**

| Physical quantity | Unit | Symbol |
|---|---|---|
| length | metre | m |
| mass | kilogram | kg |
| time | second | s |

| Physical quantity | Unit | Symbol |
|---|---|---|
| electric current | ampere | A |
| temperature difference | Kelvin | K |
| amount of substance | mole | mol |

**Derived units** Example:

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

If a car travels 2 metres in 2 seconds:

$$\text{speed} = \frac{2\ \text{metres}}{2\ \text{seconds}} = 1\frac{\text{m}}{\text{s}} = 1\text{m/s}$$

$^{-1}$ ($s^{-1}$ = 1 ). This defines the SI unit of speed to be 1 metre per second (m/s), or —
1 m s s

 http://www.oxfordsecondary.co.uk/acknowledgements

### Practice questions

1 Complete this table by filling in the missing units and symbols.

| Physical quantity | Equation used to derive unit | Unit | Symbol and name (if there is one) |
|---|---|---|---|
| frequency | $\text{period}^{-1}$ | $s^{-1}$ | Hz, hertz |
| volume | $\text{length}^3$ | | – |
| density | mass ÷ volume | | – |
| acceleration | velocity ÷ time | | – |
| force | mass × acceleration | | |
| work and energy | force × distance | | |

## 1.2 Significant figures

When you use a calculator to work out a numerical answer, you know that this often results in a large number of decimal places and, in most cases, the final few digits are 'not significant'. It is important to record your data and your answers to calculations to a reasonable number of significant figures. Too many and your answer is claiming an accuracy that it does not have, too few and you are not showing the precision and care required in scientific analysis.

Numbers to 3 significant figures (3 s.f.):

3.62 25.4 271 0.0147 0.245 39 400

(notice that the zeros before the figures and after the figures are *not* significant – they just show you how large the number is by the position of the decimal point).

Numbers to 3 significant figures where the zeros *are* significant:

207 4050 1.01 (any zeros between the other significant figures *are* significant).

Standard form numbers with 3 significant figures:

$9.42 \times 10^{-5}$ $1.56 \times 10^{8}$

If the value you wanted to write to 3.s.f. was 590, then to show the zero was significant you would have to write:

590 (to 3.s.f.) or $5.90 \times 10^2$

## *Practice questions*

2 Give these measurements to 2 significant figures:

**a** 19.47 m **b** 21.0 s **c** $1.673\times10^{-27}$ kg **d** 5 s

3 Use the equation:

$$\text{resistance} = \frac{\text{potential difference}}{\text{current}}$$

to calculate the resistance of a circuit when the potential difference is 12 V and the current is 1.8 mA. Write your answer in kΩ to 3 s.f.

### 1.3 Uncertainties

When a physical quantity is measured there will always be a small difference between the measured value and the true value. How important the difference is depends on the size of the measurement and the size of the uncertainty, so it is important to know this information when using data.

There are several possible reasons for uncertainty in measurements, including the difficulty of taking the measurement and the resolution of the measuring instrument (i.e. the size of the scale divisions).

For example, a length of 6.5 m measured with great care using a 10 m tape measure marked in mm would have an uncertainty of 2 mm and would be recorded as 6.500 ± 0.002 m.

It is useful to quote these uncertainties as percentages.

For the above length, for example,

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{measurement}}\times 100$$

$$\text{percentage uncertainty} = \frac{0.002}{6.500}\times 100\% = 0.03\%.$$ The measurement is 6.500 m ± 0.03%.

Values may also be quoted with absolute error rather than percentage uncertainty, for example, if the 6.5 m length is measured with a 5% error, the absolute error = 5/100 × 6.5 m = ±0.325 m.

## *Practice questions*

4 Give these measurements with the uncertainty shown as a percentage (to 1 significant figure):

**a** 5.7 ± 0.1 cm **b** 450 ± 2 kg **c** 10.60 ± 0.05 s **d** 366 000 ± 1000 J

5 Give these measurements with the error shown as an absolute value: **a** 1200 W ± 10% **b** 330 000 Ω ± 0.5%

6 Identify the measurement with the smallest percentage error. Show your working.

**A** 9 ± 5 mm **B** 26 ± 5 mm **C** 516 ± 5 mm **D** 1400 ± 5 mm

## 2 Standard form and prefixes

When describing the structure of the Universe you have to use very large numbers. There are billions of galaxies and their average separation is about a million light years (ly). The Big Bang theory says that the Universe began expanding about 14 billion years ago. The Sun formed about 5 billion years ago. These numbers and larger numbers can be expressed in standard form and by using prefixes.

### 2.1 Standard form for large numbers

In standard form, the number is written with one digit in front of the decimal point and multiplied by the appropriate power of 10. For example:

- The diameter of the Earth, for example, is 13 000 km.
  13 000 km = 1.3 × 10 000 km = $1.3\times10^4$ km.
- The distance to the Andromeda galaxy is 2 200 000 light years = 2.2 × 1 000 000 ly = $2.2\times10^6$ ly.

### 2.2 Prefixes for large numbers

Prefixes are used with SI units (see Topic 1.1) when the value is very large or very small. They can be used instead of writing the number in standard form. For example:

- A kilowatt (1 kW) is a thousand watts, that is 1000 W or $10^3$ W.
- A megawatt (1 MW) is a million watts, that is 1 000 000 W or $10^6$ W.
- A gigawatt (1 GW) is a billion watts, that is 1 000 000 000 W or $10^9$ W.

| Prefix | Symbol | Value |
|---|---|---|
| kilo | k | $10^3$ |
| mega | M | $10^6$ |

| Prefix | Symbol | Value |
|---|---|---|
| giga | G | $10^9$ |
| tera | T | $10^{12}$ |

For example, Gansu Wind Farm in China has an output of $6.8\times10^9$ W. This can be written as 6800 MW or 6.8 GW.

### *Practice questions*

1 Give these measurements in standard form:
**a** 1350 W **b** 130 000 Pa **c** 696 × $10^6$ s **d** 0.176 × $10^{12}$ C kg$^{-1}$

2 The latent heat of vaporisation of water is 2 260 000 J/kg. Write this in: **a** J/g
**b** kJ/kg **c** MJ/kg

### 2.3 Standard form and prefixes for small numbers

At the other end of the scale, the diameter of an atom is about a tenth of a billionth of a metre. The particles that make up an atomic nucleus are much smaller. These measurements are represented using negative powers of ten and more prefixes. For example:

- The charge on an electron = $1.6\times10^{-19}$ C.
- The mass of a neutron = 0.016 75 × $10^{-25}$ kg = $1.675\times10^{-27}$ kg (the decimal point has moved 2 places to the right).

- There are a billion nanometres in a metre, that is 1 000 000 000 nm = 1 m.
- There are a million micrometres in a metre, that is 1 000 000 μm = 1 m.

| Prefix | Symbol | Value |
|---|---|---|
| centi | c | $10^{-2}$ |
| milli | m | $10^{-3}$ |
| micro | μ | $10^{-6}$ |

| Prefix | Symbol | Value |
|---|---|---|
| nano | n | $10^{-9}$ |
| pico | p | $10^{-12}$ |
| femto | f | $10^{-15}$ |

### *Practice questions*

3 Give these measurements in standard form:

**a** 0.0025 m **b** $160 \times 10^{-17}$ m **c** $0.01 \times 10^{-6}$ J **d** $0.005 \times 10^{6}$ m **e** $0.00062 \times 10^{3}$ N

4 Write the measurements for question 3a, c, and d above using suitable prefixes.

5 Write the following measurements using suitable prefixes.

**a** a microwave wavelength = 0.009 m **b** a wavelength of infrared = $1\times10^{-5}$ m **c** a wavelength of blue light = $4.7\times10^{-7}$ m

## 2.4 Powers of ten

When multiplying powers of ten, you must *add* the indices. So

$100 \times 1000 = 100\,000$ is the same as $10^2 \times 10^3 = 10^{2+3} = 10^5$

When dividing powers of ten, you must *subtract* the indices.

So $\frac{100}{1000} = \frac{1}{10} = 10^{-1}$ is the same as $\frac{10^2}{10^3} = 10^{2-3} = 10^{-1}$

But you can only do this when the numbers with the indices are the same.

So $10^2 \times 2^3 = 100 \times 8 = 800$

And you can't do this when adding or subtracting.

$10^2 + 10^3 = 100 + 1000 = 1100$

$10^2 - 10^3 = 100 - 1000 = -900$

**Remember:** You can only add and subtract the indices when you are multiplying or dividing the numbers, not adding or subtracting them.

### *Practice questions*

6 Calculate the following values – read the questions very carefully!

**a** $20^6 + 10^{-3}$ **b** $10^2 - 10^{-2}$ **c** $2^3 \times 10^2$ **d** $10^5 \div 10^2$

7 The speed of light is $3.0\times10^8$ m s$^{-1}$. Use the equation $v = f\lambda$ (where λ is wavelength) to calculate the frequency of:

**a** ultraviolet,
wavelength $3.0\times10^{-7}$ m
**b** radio waves,
wavelength 1000 m **c**
X-rays, wavelength
$1.0\times10^{-10}$ m.

## 3 Rearranging equations

Sometimes you will need to rearrange an equation to calculate the answer to a question. For example, if you want to calculate the resistance $R$, the equation:

potential difference ($V$) = current ($A$) × resistance (Ω) or $V = I R$

must be rearranged to make $R$ the subject of the equation:

$$R = \frac{V}{I}$$

When you are solving a problem:

- Write down the values you know and the ones you want to calculate.
- you can rearrange the equation first, and then substitute the values *or*
- substitute the values and then rearrange the equation

### 3.1 Substitute and rearrange

A student throws a ball vertically upwards at 5 m $s^{-1}$. When it comes down, she catches it at the same point. Calculate how high it goes.

**Step 1:** Known values are:

- initial velocity $u$ = 5.0 m $s^{-1}$
- final velocity $v$ = 0 (you know this because as it rises it will slow down, until it comes to a stop, and then it will start falling downwards)
- acceleration $a = g = -9.81$ m $s^{-2}$
- distance $s$ = ?

**Step 2:** Equation:

(final velocity)$^2$ – (initial velocity)$^2$ = 2 × acceleration × distance

or $v^2 - u^2 = 2 \times g \times s$

Substituting: $(0)^2 - (5.0 \text{ m s}^{-1})^2 = 2 \times -9.81 \text{ m s}^{-2} \times s$

$0 - 25 = 2 \times -9.81 \times s$ **Step 3:**

Rearranging: $-19.62\ s = -25$ $s =$

$$\frac{-25}{-19.62} = 1.27 \text{ m} = 1.3 \text{ m (2 s.f.)}$$

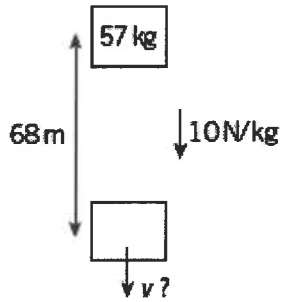
### *Practice questions*

**1** The potential difference across a resistor is 12 V and the current through it is 0.25 A. Calculate its resistance.

2 Red light has a wavelength of 650 nm. Calculate its frequency. Write your answer in standard form.
(Speed of light = $3.0 \times 10^8$ m s$^{-1}$)

## 3.2 Rearrange and substitute

A 57 kg block falls from a height of 68 m. By considering the energy transferred, calculate its speed when it reaches the ground.




(Gravitational field strength = 10 N kg$^{-1}$)

**Step 1:** $m$ = 57 kg  $h$ = 68 m  $g$ = 10 N kg$^{-1}$  $v$ = ?

**Step 2:** There are three equations:

PE = $m\,g\,h$  KE gained = PE lost  KE = 0.5 $m\,v^2$ **Step 3:**

Rearrange the equations before substituting into it.

As KE gained = PE lost, $m\,g\,h = 0.5\,m\,v^2$

You want to find $v$. Divide both sides of the equation by 0.5 $m$:

$$\frac{mgh}{0\,5.\,m} = \frac{0\,5.\,mv^2}{0\,5.\,m}$$

$2\,g\,h = v^2$
To get $v$, take the square root of both sides: $v = \sqrt{2gh}$

**Step 4:** Substitute into the equation:

$v = \sqrt{2\ 10\ 68 \times} \times$

$v = \sqrt{1360} = 37$ m s$^{-1}$

## *Practice questions*

3 Calculate the specific latent heat of fusion for water from this data:
$4.03 \times 10^4$ J of energy melted 120 g of ice.
Use the equation:
thermal energy for a change in state (J) = mass (kg) × specific latent heat (J kg$^{-1}$) Give your answer in J kg$^{-1}$ in standard form.

Double BTEC Science Optional Tasks

Physics

# Suggested activities

## 4 Work done, power, and efficiency

### 4.1 Work done

Work is done when energy is transferred. Work is done when a force makes something move. If work is done *by* an object its energy decreases and if work is done *on* an object its energy increases.

work done = energy transferred = force × distance

Work and energy are measured in joules (J) and are scalar quantities (see Topic 3.1).

### *Practice questions*

1 Calculate the work done when the resultant force on a car is 22 kN and it travels 2.0 km.

2 Calculate the distance travelled when 62.5 kJ of work is done applying a force of 500 N to an object.

### 4.2 Power

Power is the rate of work done.

It is measured in watts (W) where 1 watt = 1 joule per second.

$$\text{power} = \frac{\text{energy transferred}}{\text{time taken}} \quad \textit{or} \quad \text{power} = \frac{\text{work done}}{\text{time taken}}$$

$P = \Delta W / \Delta t$ *Δ is the symbol 'delta' and is used to mean a 'change in'*

Look at this worked example, which uses the equation for potential energy gained.

A motor lifts a mass $m$ of 12 kg through a height $\Delta h$ of 25 m in 6.0 s.

Gravitational potential energy gained:

$\Delta PE = mg\Delta h = (12\ \text{kg}) \times (9.81\ \text{m s}^{-2}) \times (25\ \text{m}) = 2943\ \text{J}$

$$\text{Power} = \frac{2943\ \text{J}}{6.0\ \text{s}} = 490\ \text{W (2 s.f.)}$$

### *Practice questions*

3 Calculate the power of a crane motor that lifts a weight of 260 000 N through 25 m in 48 s.

4 A motor rated at 8.0 kW lifts a 2500 N load 15 m in 5.0 s. Calculate the output power.

### 4.3 Efficiency

Whenever work is done, energy is transferred and some energy is transferred to other forms, for example, heat or sound. The efficiency is a measure of how much of the energy is transferred usefully.

Efficiency is a ratio and is given as a decimal fraction between 0 (all the energy is wasted) and 1 (all the energy is usefully transferred) or as a percentage between 0 and 100%. It is not possible for anything to be 100% efficient: some energy is always lost to the surroundings.

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \text{ or Efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

(multiply by 100% for a percentage)

Look at this worked example.

A thermal power station uses 11 600 kWh of energy from fuel to generate electricity. A total of 4500 kWh of energy is output as electricity. Calculate the percentage of energy 'wasted' (dissipated in heating the surroundings).

You must calculate the energy wasted using the value for useful energy output:

$$\text{percentage energy wasted} = \frac{\text{(total energy input - energy output as electricity)}}{\text{total energy input}} \times 100$$

$$\text{percentage energy wasted} = \frac{(11600 - 4500)}{11600} \times 100 = 61.2\% = 61\% \text{ (2 s.f.)}$$

### *Practice questions*

**5** Calculate the percentage efficiency of a motor that does 8400 J of work to lift a load. The electrical energy supplied is 11 200 J.

**6** An 850 W microwave oven has a power consumption of 1.2 kW. Calculate the efficiency, as a percentage.

**7** Use your answer to question 4 above to calculate the percentage efficiency of the motor. (The motor, rated at 8.0 kW, lifts a 2500 N load 15 m in 5.0 s.)

**8** Determine the time it takes for a 92% efficient 55 W electric motor take to lift a 15 N weight 2.5 m.

# Answers to maths skills practice questions

## 1 Measurements

1

| Physical quantity | Equation used to derive unit | Unit | Symbol and name (if there is one) |
|---|---|---|---|
| frequency | period$^{-1}$ | $s^{-1}$ | Hz, hertz |
| volume | length$^3$ | $m^3$ | – |
| density | mass ÷ volume | kg $m^{-3}$ | – |
| acceleration | velocity ÷ time | m $s^{-2}$ | – |
| force | mass × acceleration | kg m $s^{-2}$ | N newton |
| work and energy | force × distance | N m (or kg $m^2$ $s^{-2}$) | J joule |

2 **a** 19 m **b** 21 s **c** $1.7 \times 10^{-27}$ kg **d** 5.0 s

3 Resistance = $\frac{12\text{ V}}{1.8\text{ mA}} = \frac{12\text{ V}}{0.0018\text{ A}}$ = 6666.666...Ω= 6.66666...kΩ= 6.67Ω

4 **a** 5.7 cm ± 2% **b** 450 kg ± 0.4% **c** 10.6 s ± 0.5% **d** 366 000 J ± 0.3%

5 **a** 1200 ± 120 W **b** 330 000 ± 1650 Ω

6 **D** 1400 ± 5 mm (Did you calculate them all? The same absolute error means the percentage error will be smallest in the largest measurement, so no need to calculate.)

## 2 Standard form and prefixes

1 **a** $1.35\times10^3$ W (or $1.350 \times 10^3$ W to 4 s.f.) **b** $1.3\times10^5$ Pa
**c** $6.96\times10^8$ s **d** $1.76\times10^{11}$ C $kg^{-1}$

2 **a** 2 260 000 J in 1 kg, so there will be 1000 times fewer J in 1 g: $\frac{2\,260\,000}{1000}$ = 2260 J/g

**b** 1 kJ = 1000 J, 2 260 000 J/kg = $\frac{2\,260\,000}{1000}$ kJ/kg = 2260 kJ/kg

**c** 1 MJ = 1000 kJ, so 2260 kJ/kg = $\frac{2260}{1000}$ MJ/kg = 2.26 MJ/kg

3 **a** $2.5\times10^{-3}$ m **b** $1.60\times10^{-15}$ m **c** $1\times10^{-8}$ J
**d** $5\times10^3$ m **e** $6.2 \times 10^{-1}$ N

4 **a** 2.5 µm **b** 1.60 f m **c** 10 nJ **or** 0.01 µJ
**d** 5 km
**e** 0.62 N **or** 62 cN

5 **a** 0.009 m = $9\times10^{-3}$ m = 9 mm **b** $1\times10^{-5}$ m = $1 \times 10 \times 10^{-6}$ m = $10 \times 10^{-6}$ m = 10 µm **c** $4.7\times10^{-7}$ m = $4.7 \times 100 \times 10^{-9}$ m = $470 \times 10^{-9}$ m = 470 nm

6 **a** 64000000 **or** $6.4 \times 10^7$ **b** 99.99

c 800 d $10^3$

7 a $3.0\times10^8$ m $s^{-1}$ ÷ $3.03\times10^{-7}$ m = $1.0\times10^{15}$ Hz b $3.0\times10^8$ m $s^{-1}$ ÷ 1000 m = $3.0\times10^5$ Hz

c $3.0\times10^8$ m $s^{-1}$ ÷ $1.0\times10^{-10}$ m = $3.0\times10^{18}$ Hz

## 3 Rearranging equations

1 $V = 12$ V and $I = 0.25$ A

$V = IR$ so $12 = 0.25 \times R$

$$R = \frac{V}{I} = \frac{12}{0.25} = 48\ \Omega$$

2 $\lambda = 650$ nm = $650\times10^{-9}$ m and $v = 3.0\times10^8$ m/s
$v = f\lambda$ so $3.0\times10^8 = f \times 650\times10^{-9}$

$$f = \frac{v}{\lambda} = \frac{3.0\times10^8}{650\times10^{-9}} = 0.00462\times10^{17} = 4.62\times10^{14}\ \text{Hz}$$

3 $E = 4.01\times10^4$ J and $m = 0.120$ g = 0.120 kg $E = mL$ so $4.01\times10^4 = 0.120 \times L$

$L = \frac{E}{m} = \frac{4.01\times10^4}{0.120} =$ ~~334 166 J/kg~~ = $3.34\times10^5$ J/kg in standard form

## 4 Work done, power, and efficiency

1 $22\times10^3$ N × $2\times10^3$ m = 44 000 000 J = 44 MJ

2 $\frac{62.5\times10^3\ \text{J}}{500\ \text{N}}$ = 125 m

3 $\frac{260\,000\ \text{N} \times 25\ \text{m}}{48\ \text{s}}$ = 13 541.6 W = 14 000 W or 14 kW (2 s.f.)

4 $\frac{2500\ \text{N} \times 15\ \text{m}}{5\ \text{s}}$ = 7500 W = 7.5 kW

5 $\frac{8400}{11200} \times 100 = 75\%$

6 $\frac{850}{1.2\times10^3} \times 100 = 71\%$

7 $\frac{7.5}{8.0} \times 100 = 94\%$

8 0.74 s