Alleyne's
ACADEMY
NISI DOMINUS FRUSTRA - 1558

Y12 Physics Bridging Project

Transition activities

The following activities cover some of the key skills from GCSE science that will be relevant at AS and A-level. They include the vocabulary used when working scientifically and some maths and practical skills.

You can do these activities independently or in class. The booklet has been produced so you can complete it electronically or print it out and do the activities on paper.

The activities are **not a test**. Try the activities first and see what you remember and then use textbooks or other resources to answer the questions. **Don't** just go to Google for the answers, as actively engaging with your notes and resources from GCSE will make this learning experience much more worthwhile.

The answers will be given on the first lesson of your a-level Physics class in September. You need to bring it with you to the first lesson to be marked and to highlight any areas that you need to focus on moving forward.

Activity 1 Scientific vocabulary: Making measurements

Link each term on the left to the correct definition on the right.

True value	The range within which you would expect the true value to lie
Accurate	A measurement that is close to the true value
Resolution	Repeated measurements that are very similar to the calculated mean value
Precise	The value that would be obtained in an ideal measurement where there were no errors of any kind
Uncertainty	The smallest change that can be measured using the measuring instrument that gives a readable change in the reading

Activity 2 Scientific vocabulary: Errors

Link each term on the left to the correct definition on the right.

Random error	Causes readings to differ from the true value by a consistent amount each time a measurement is made
Systematic error	When there is an indication that a measuring system gives a false reading when the true value of a measured quantity is zero
Zero error	Causes readings to be spread about the true value, due to results varying in an unpredictable way from one measurement to the next

Understanding and using SI units

All measurements have a size (eg 2.7) and a unit (eg metres or kilograms). Sometimes, there are different units available for the same type of measurement. For example, milligram, gram, kilogram and tonne are all units used for mass. Some values like strain and refractive index are not followed by a unit.

To reduce confusion, and to help with conversion between different units, there is a standard system of units called the SI units which are used for most scientific purposes.

These units have all been defined by experiment so that the size of, say, a metre in the UK is the same as a metre in China.

There are seven SI base units, which are given in the table.

Physical quantity	Unit	Abbreviation
Mass	kilogram	kg
Length	metre	m
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
luminous intensity	candela	cd

All other units can be derived from the SI base units. For example, area is measured in metres square (written as m^2) and speed is measured in metres per second (written as $m\ s^{-1}$ this is a change from GCSE, where it would be written as m/s).

Some derived units have their own unit names and abbreviations, often when the combination of SI units becomes complicated. Some common derived units are given in the table below.

Physical quantity	Unit	Abbreviation	SI unit
Force	newton	N	$kg\ m\ s^{-2}$
Energy	joule	J	$kg\ m^2\ s^{-2}$
Frequency	hertz	Hz	s^{-1}

Using prefixes and powers of ten

Very large and very small numbers can be complicated to work with if written out in full with their SI unit. For example, measuring the width of a hair or the distance from Manchester to London in metres (the SI unit for length) would give numbers with a lot of zeros before or after the decimal point, which would be difficult to work with.

So, we use prefixes that multiply or divide the numbers by different powers of ten to give numbers that are easier to work with. You will be familiar with the prefixes milli (meaning 1/1000), centi (1/100), and kilo (1 × 1000) from millimetres, centimetres and kilometres.

There is a wide range of prefixes. Most of the quantities in scientific contexts will be quoted using the prefixes that are multiples of 1000. For example, we would quote a distance of 33 000 m as 33 km.

Kg is the only base unit with a prefix.

The most common prefixes you will encounter are given in the table.

Prefix	Symbol	Power of 10	Multiplication factor	
Tera	T	10^{12}	1 000 000 000 000	
Giga	G	10^{9}	1 000 000 000	
Mega	M	10^{6}	1 000 000	
kilo	k	10^{3}	1000	
deci	d	10^{-1}	0.1	1/10
centi	c	10^{-2}	0.01	1/100
milli	m	10^{-3}	0.001	1/1000
micro	μ	10^{-6}	0.000 001	1/1 000 000
nano	n	10^{-9}	0.000 000 001	1/1 000 000 000
pico	p	10^{-12}	0.000 000 000 001	1/1 000 000 000 000
femto	f	10^{-15}	0.000 000 000 000 001	1/1 000 000 000 000 000

Activity 3 SI units and prefixes

1. Re-write the following quantities using the correct SI units.

    a. 1 minute
    b. 1 milliamp
    c. 1 tonne

2. What would be the most appropriate unit to use for the following measurements?

    a. The wavelength of a wave in a ripple tank
    b. The temperature of a thermistor used in hair straighteners
    c. The half-life of a source of radiation used as a tracer in medical imaging
    d. The diameter of an atom
    e. The mass of a metal block used to determine its specific heat capacity
    f. The current in a simple circuit using a 1.5 V battery and bulb

Activity 4 Converting data

Re-write the following quantities.

1. 1.5 kilometres in metres

2. 450 milligrams in kilograms

3. 96.7 megahertz in hertz

4. 5 nanometers in metres

5. 3.9 gigawatts in watts

Greek letters

Greek letters are used often in science. They can be used:

- as symbols for numbers (such as π = 3.14…)
- as prefixes for units to make them smaller (eg μm = 0.000 000 001 m)
- as symbols for particular quantities.

The Greek alphabet is shown below.

Capital letter	Lower case letter	Name
Α	α	alpha
Β	β	beta
Γ	γ	gamma
Δ	δ	delta
Ε	ε	epsilon
Ζ	ζ	zeta
Η	η	eta
Θ	θ	theta

Capital letter	Lower case letter	Name
Ι	ι	iota
Κ	κ	kappa
Λ	λ	lambda
Μ	μ	mu
Ν	ν	nu
Ξ	ξ	ksi
Ο	ο	omicron
Π	π	pi

Capital letter	Lower case letter	Name
Ρ	ρ	rho
Σ	ς or σ	sigma
Τ	τ	tau
Υ	υ	upsilon
Φ	φ	phi
Χ	χ	chi
Ψ	ψ	psi
Ω	ω	omega

Activity 5 Using Greek letters

Use your knowledge from GCSE to complete the table. The first line has been completed for you.

Object or quantity represented by the Greek letter	Greek letter
Wavelength	λ
Type of ionising radiation which cannot pass through paper and is used in smoke detectors	
	Ω
Type of ionising radiation which is an electron ejected from the nucleus. Can be used to monitor paper thickness	
Very short wavelength electromagnetic wave	

The Physics formula and data sheet

You will need to use the AQA Physics formula and data sheet in your exams.

Activity 6 Using the Physics formula and data sheet
1. Use the sheet to find the symbols used to represent the following particles. (You will learn about these particles when you study particle physics.) a. Photon b. Neutrino c. Muon d. Meson (two letters used depending on type of meson) 2. Look through the Electricity and Materials formula sections on the data sheet. There is one Greek letter that is used to represent two different quantities. Give the letter and the quantities is it used to represent.

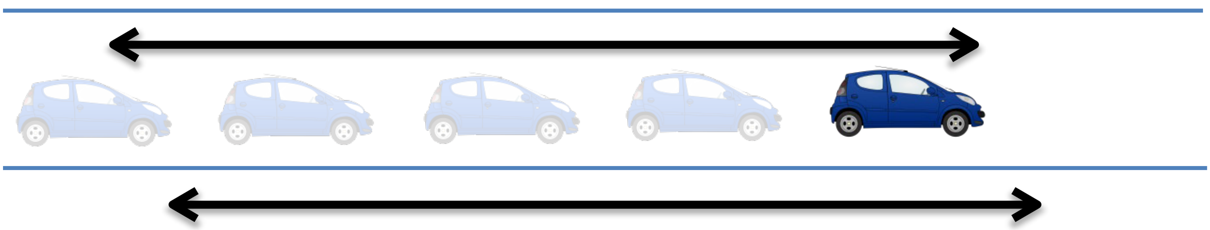
The delta symbol (Δ)

The delta symbol (Δ) is used to mean 'change in'. For example, at GCSE, you would have learned the formula:

$$\text{speed} = \frac{\text{distance}}{\text{time}} \quad \text{which can be written as} \quad s = \frac{d}{t}$$

What you often measure is the **change** in the distance of the car from a particular point, and the **change** in time from the beginning of your measurement to the end of it.

change in distance along road



change in time

time at starting point of measurement

time at end point of measurement

As the distance and the speed are changing, you use the delta symbol to emphasise this. The A-level version of the above formula becomes:

$$\text{velocity} = \frac{\text{displacement}}{\text{time}} \quad \text{which can be written as} \quad v = \frac{\Delta s}{\Delta t}$$

Note: the delta symbol is a property of the quantity it is with, so you treat 'Δs' as one thing when rearranging, and you cannot cancel the delta symbols in the equation above.

Activity 7 Using the delta symbol

1. What is the difference between:

   a. **speed** and **velocity**
   b. **distance** and **displacement**

2. Look at the A-level Physics formula sheet .

   Which equations look similar to ones you used at GCSE, but now include the delta symbol?

3. A coffee machine heats water from 20 °C to 90 °C.

   The power output of the coffee machine is 2.53 kW.

   The specific heat capacity of water is 4200 J/kg °C

   Calculate the mass of water that the coffee machine can heat in 20 s.

4. An unused pencil has a length of 86.0 mm.

   A student uses the pencil to draw 20 lines on a piece of paper.

   Each line has a length of 25 cm.

   The length of the pencil has changed to 84.5 mm.

   Calculate the length of line that would need to be drawn for the original length to be halved.

Rearranging formulas

Activity 8 Rearranging formulas
1. Rearrange $c = f\lambda$ to make f the subject. 2. Rearrange $\rho = \frac{m}{V}$ to make m the subject. 3. Rearrange $w = \frac{\lambda D}{s}$ to make s the subject 4. Rearrange $P = I^2 R$ to make I the subject 5. Rearrange $E = \frac{1}{2} m v^2$ to make v the subject. 6. Rearrange $h f = \varphi + E_k$ to make φ the subject 7. Rearrange $v = u + a t$ to make a the subject. 8. Rearrange $s = u t + \frac{1}{2} a t^2$ to make a the subject. 9. Rearrange $\varepsilon = I(R + r)$ to make r the subject. 10. Rearrange $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ to make T the subject.

Using math’s skills

Physics uses the language of mathematics to make sense of the world. It is important that you are able to apply maths skills in Physics. The maths skills you learnt and applied at GCSE are used and developed further at A-level.

Activity 9 Standard form
1. Write the following numbers in standard form. a. 379 4 b. 0.0712 2. Use the data sheet to write the following as ordinary numbers. a. The speed of light b. The charge on an electron 3. Write one quarter of a million in standard form. 4. Write these constants in ascending order (ignoring units). Permeability of free space The Avogadro constant Proton rest mass Acceleration due to gravity Mass of the Sun

Activity 10 Significant figures and rounding

1. A rocket can hold 7 tonnes of material.

   Calculate how many rockets would be needed to deliver 30 tonnes of material to a space station.

2. A power station has an output of 3.5 MW.

   The coal used had a potential output of 9.8 MW.

   Calculate the efficiency of the power station.

   Give your answer as a percentage to an appropriate number of significant figures.

3. A radioactive source produces 17 804 beta particles in 1 hour.

   Calculate the mean number of beta particles produced in 1 minute.

   Give your answer to one significant figure.

Activity 11 Fractions, ratios and percentages

1. The ratio of turns of wire on a transformer is 350 : 7000 (input : output)

   What fraction of the turns are on the input side?

2. A bag of electrical components contains resistors, capacitors and diodes.

   $^{2}/_{5}$ of the components are resistors.

   The ratio of capacitors to diodes in a bag is 1 : 5. There are 100 components in total.

   How many components are diodes?

3. The number of coins in two piles are in the ratio 5 : 3. The coins in the first pile are all 50p coins. The coins in the second pile are all £1 coins.

   Which pile has the most money?

4. A rectangle measures 3.2 cm by 6.8 cm. It is cut into four equal sized smaller rectangles.

   Work out the area of a small rectangle.

5. Small cubes of edge length 1 cm are put into a box. The box is a cuboid of length 5 cm, width 4 cm and height 2 cm.

   How many cubes are in the box if it is half full?

6. In a circuit there are 600 resistors and 50 capacitors. 1.5% of the resistors are faulty. 2% of the capacitors are faulty.

   How many faulty components are there altogether?

7. How far would you have to drill in order to drill down 2% of the radius of the Earth?

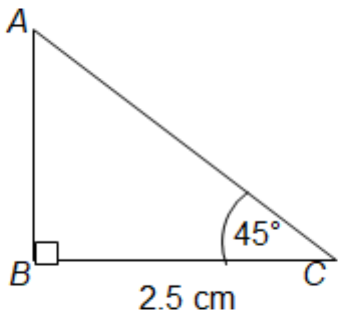
8. Power station A was online 94% of the 7500 days it worked for.

   Power station B was online $^{8}/_{9}$ of the 9720 days it worked for.

   Which power station was offline for longer?

Activity 12 Using sine, cosine and tangent

1. Calculate length AB



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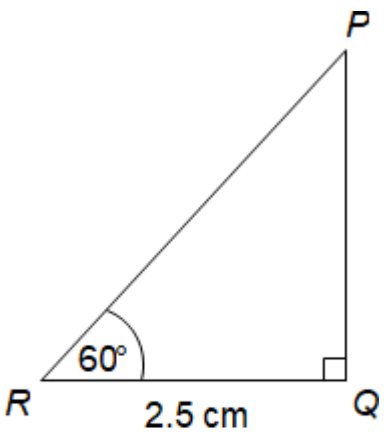
2. Calculate length PR



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Activity 13 Arithmetic means

1. The mean mass of 9 people is 79 kg.

   A 10th person is such that the mean mass increases by 1 kg

   What is the mass of the 10th person?

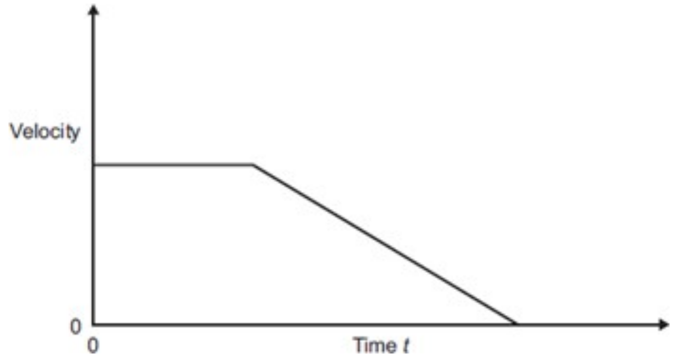
2. A pendulum completes 12 swings in 150 s.

   Calculate the mean swing time.

Activity 14 Gradients and areas

1. A car is moving along a road. The driver sees an obstacle in the road at time $t = 0$ and applies the brakes until the car stops.

   The graph shows how the velocity of the car changes with time.

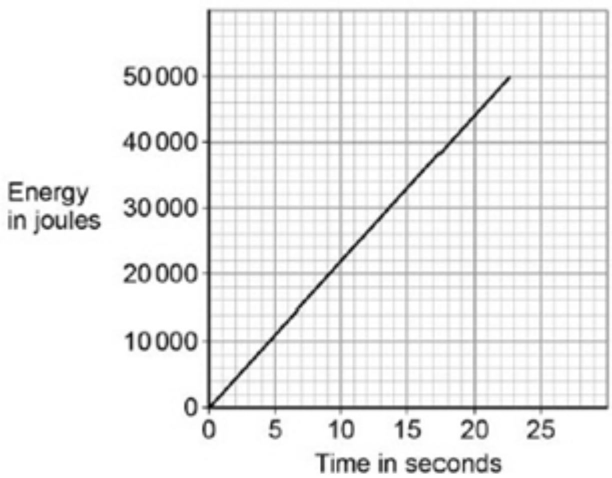


From the list below, which letter represents:

- the negative acceleration of the car
- the distance travelled by the car?

a. The area under the graph
b. The gradient of the sloping line
c. The intercept on the y axis

2. The graph shows how the amount of energy transferred by a kettle varies with time.



The power output of the kettle is given by the gradient of the graph.

Calculate the power output of the kettle.

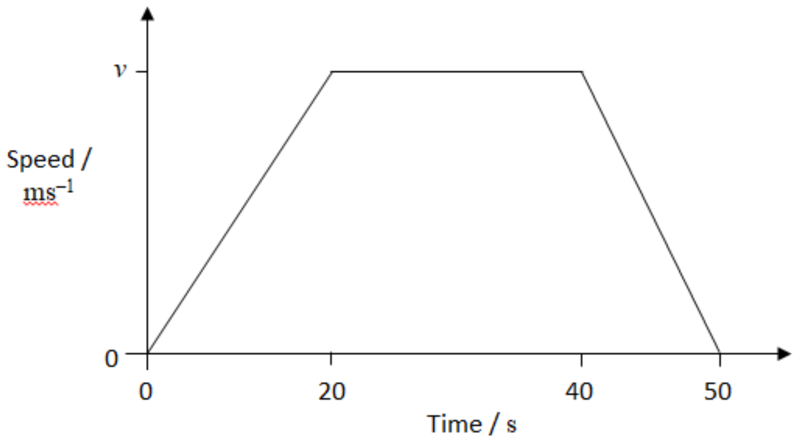
Activity 14 Gradients and areas

3. The graph shows the speed of a car between two sets of traffic lights.

   It achieves a maximum speed of *v* metres.

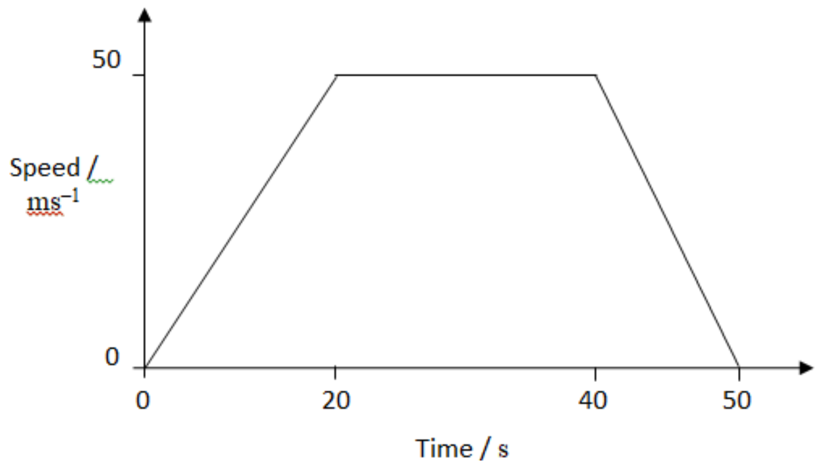
   per second. It travels for 50 seconds.

   The distance between the traffic lights is 625 metres.

   Calculate the value of v.

4. The graph shows the speed of a train between two stations.

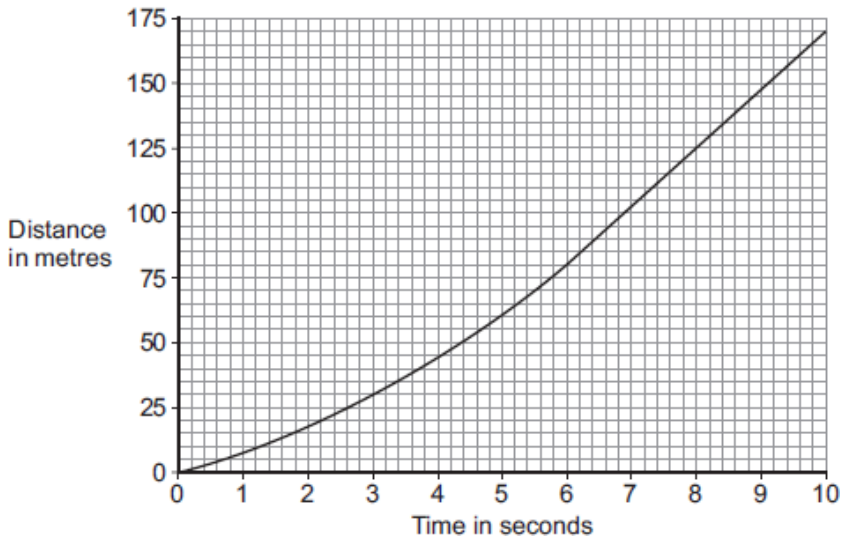
   (not drawn accurately)

   Calculate the distance between the stations.

Activity 15 Using and interpreting data in tables and graphs

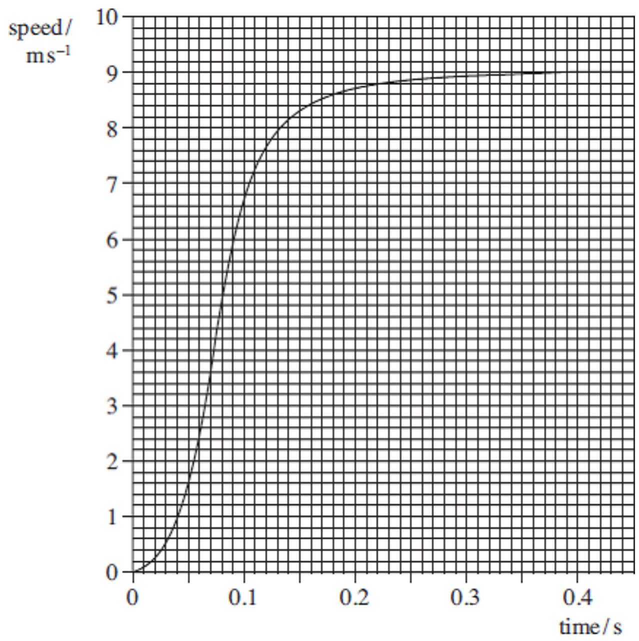
1. The graph shows the motion of a car in the first 10 seconds of its journey.

Figure 1



Use the graph to calculate the maximum speed the car was travelling at.

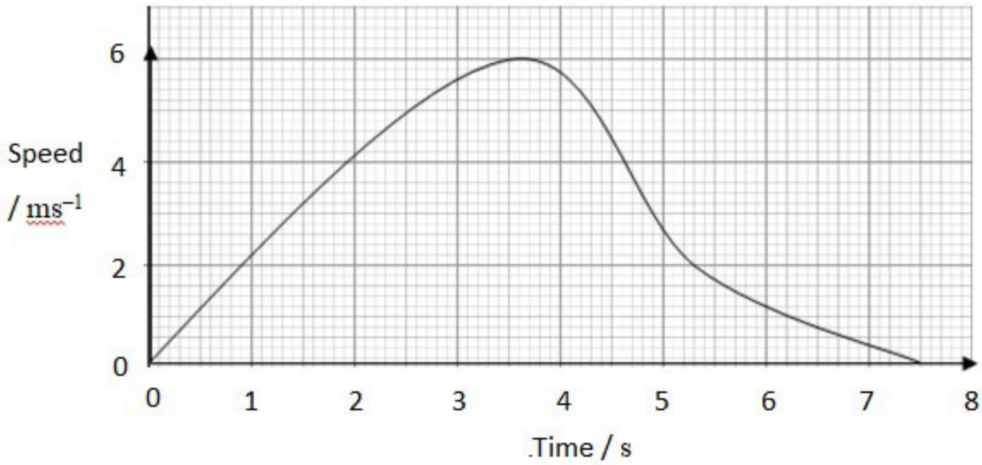
2. The figure below is a speed–time graph for a sprinter at the start of a race.



Determine the distance covered by the sprinter in the first 0.3 s of the race.

Activity 15 Using and interpreting data in tables and graphs

3. The graph shows the speed–time graph of a car.

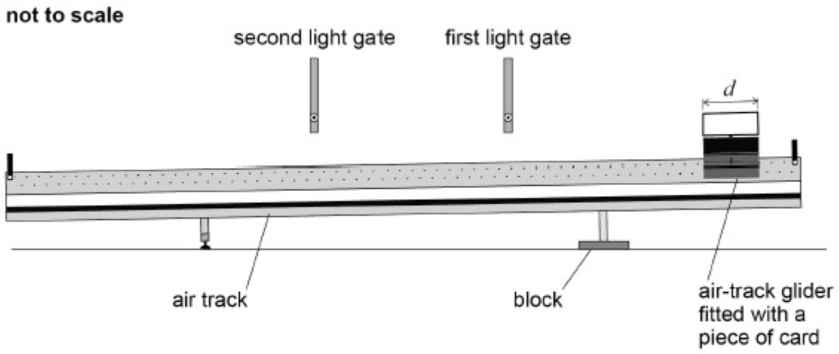


Use the graph to determine:

a. the maximum speed of the car
b. the total distance travelled
c. the average speed for the journey.

Activity 15 Using and interpreting data in tables and graphs

4. The diagram shows the apparatus used by a student to measure the acceleration due to gravity (g).



In the experiment:

- a block is used to raise one end of the air track
- an air-track glider is released from rest near the raised end of the air track and passes through the first light gate and then through the second light gate
- a piece of card of length d fitted to the air-track glider interrupts a light beam as the air-track glider passes through each light gate
- a data logger records the time taken by the piece of card to pass through each light gate and also the time for the piece of card to travel from one light gate to the other.

a. The table gives measurements recorded by the data logger.

Time to pass through first light gate / s	Time to pass through second light gate / s	Time to travel from first to second light gate / s
0.50	0.40	1.19

The length d of the piece of card is 10.0 cm.

Assume there is negligible change in velocity while the air-track glider passes through a light gate.

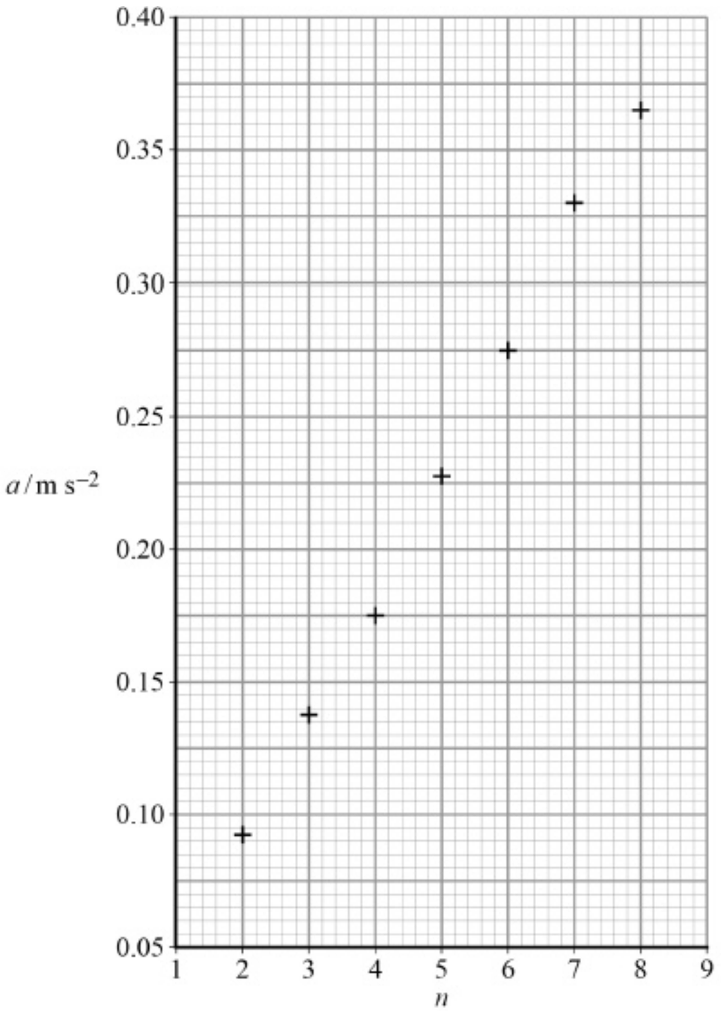
Determine the acceleration a of the air-track glider.

b. Additional values for the acceleration of the air-track glider are obtained by further raising the end of the air track by using a stack consisting of identical blocks.

Adding each block to the stack raises the end of the air track by the same distance.

Activity 15 Using and interpreting data in tables and graphs

Below is a graph of these results showing how *a* varies with *n*, the number of blocks in the stack.



Draw a line of best fit and then determine the gradient of your line (A).

c. It can be shown that, for the apparatus used by the student, g is equal to $\frac{2A}{h}$ where h is the thickness of each block used in the experiment.

The student obtains a value for g of 9.8 m s^{-2}

Calculate h.

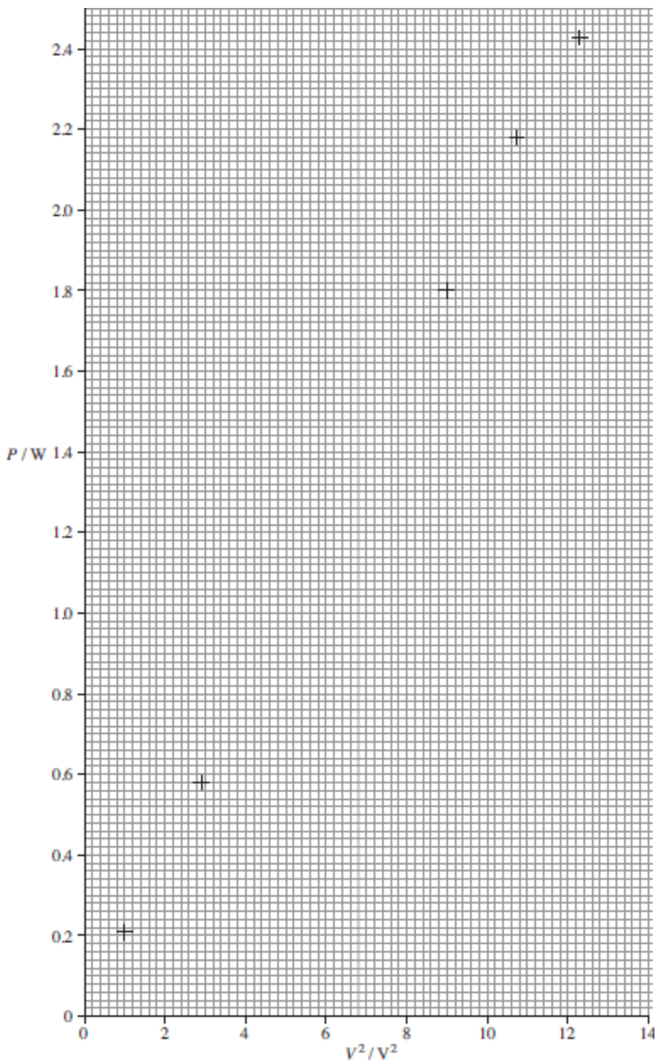
Activity 15 Using and interpreting data in tables and graphs

5. The power P dissipated in a resistor of resistance R is measured for a range of values of the potential difference V across it. The results are shown in the table.

V / V	V^2 / V^2	P / W
1.00	1.0	0.21
1.71	2.9	0.58
2.25		1.01
2.67		1.43
3.00	9.0	1.80
3.27	10.7	2.18
3.50	12.3	2.43

a. Complete the table.

b. Complete the graph below, and draw a line of best fit.



Activity 15 Using and interpreting data in tables and graphs

c. Determine the gradient of the graph.

d. Use the gradient of the graph to obtain a value for *R*.

The relationship is power = potential difference ^{2} / resistance

6. To answer these questions, you will need a copy of the A-level Physics formula sheet.
7. Use the equation for wave speed to find the frequency in the table. You will need the value for the speed of light.

In an experiment, a set of LEDs that emitted light of different colours was used.

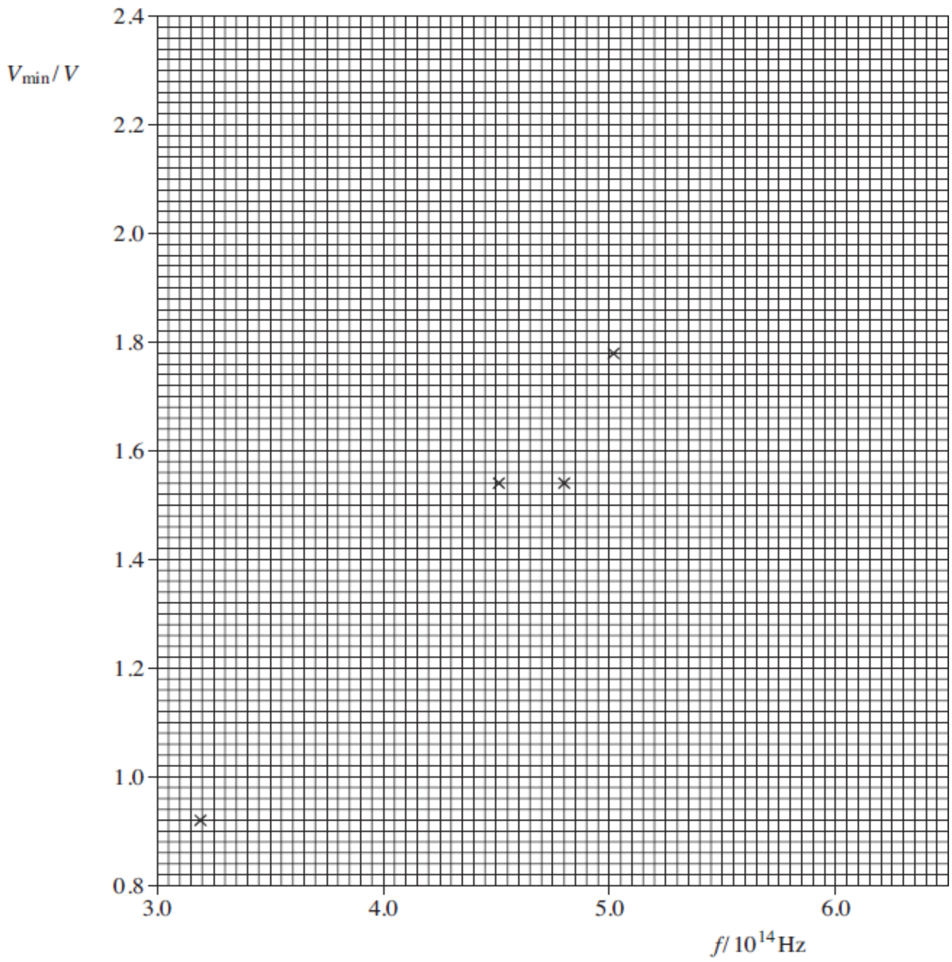
The table below shows the data collected.

Colour	Wavelength λ / nm	Frequency f / 10^{14} Hz	Minimum pd V_{min} /V
Infrared	940	3.19	0.92
Red	665	4.51	1.54
Orange	625	4.80	1.54
Yellow	595	5.04	1.78
Green	565		1.87
Blue	470		2.37

a. Complete the missing values for frequency.

b. Complete the graph by plotting the missing two points and drawing a line of best fit.

Activity 15 Using and interpreting data in tables and graphs



c. Determine the gradient of the graph.

d. Theory predicts that the energy lost by the electron in passing through the LED is the energy of the emitted photon. Hence

$eV_{min} = hf$,

where h is the Planck constant and $e = 1.60 \times 10^{-19}$ C.

Find a value for h by using the general equation of a straight line, $y = mx + c$, and your answer to part (c).

e. The accepted value for $h = 6.63 \times 10^{-34}$ J s. Calculate the percentage difference between the value calculated in part (d) and the accepted value.

New A-Level content

For the next activities you will need to make flashcards, a mind-map or a revision technique that you prefer. This is content that will be assessed in the first half-term of Y12.

Activity 16 Longitudinal and transverse waves

Longitudinal waves are waves in which the direction of vibration of the particles is **parallel** to (along) the direction in which the wave travels. Sound waves, primary seismic waves and compression waves on a slinky toy are all longitudinal waves. Figure 2 shows how to send longitudinal waves along a slinky. When one end of the slinky is moved to and fro repeatedly, each 'forward' movement causes a compression wave to pass along the slinky as the coils push into each other. Each 'reverse' movement causes the coils to move apart so rarefaction (expansion) wave passes along the slinky.

Transverse waves are waves in which the direction of vibration is **perpendicular** to the direction in which the wave travels. Electromagnetic waves, secondary seismic waves, and waves on a string or a wire are all transverse waves.

Figure 3 shows transverse waves travelling along a rope. When one end of the rope is moved from side to side repeatedly, these sideways movements travel along the rope, as each unaffected part of the rope is pulled sideways when the part next to it moves sideways.

Activity 16 Longitudinal and transverse waves

1 Classify the following types of waves as either longitudinal or transverse: **a** radio waves, **b** microwaves, **c** sound waves, **d** secondary seismic waves.

2 Sketch a snapshot of a longitudinal wave travelling on a slinky coil, indicating the direction in which the wave is travelling and areas of high density (compression) and low density (rarefaction).

3 Sketch a snapshot of a transverse wave travelling along a rope, indicating the direction in which the wave is travelling and the direction of motion of the particles at the points of zero displacement.

Activity 17 Polarisation

Transverse waves are **plane-polarised** if the vibrations stay in one plane only. If the vibrations change from one plane to another, the waves are **unpolarised**. Longitudinal waves cannot be polarised.

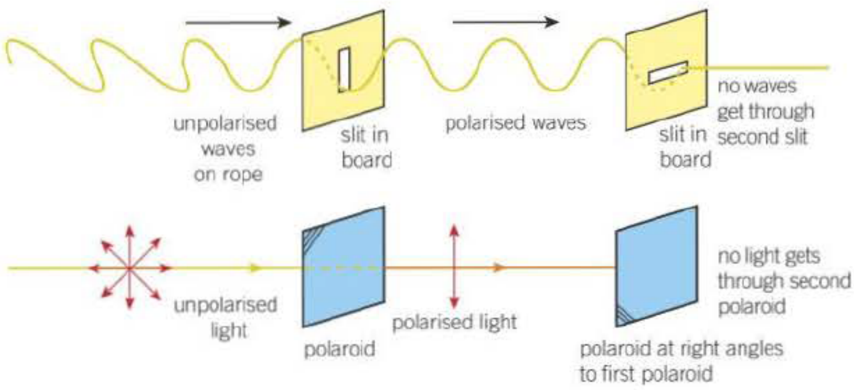
Figure 4 shows unpolarised waves travelling on a rope. When they pass through a slit in a board, as in Figure 4, they become polarised because only the vibrations parallel to the slit pass through it.

Light from a filament lamp or a candle is unpolarised. If unpolarised light is passed through a polaroid filter, the transmitted light is polarised as the filter only allows through light which vibrates in a certain direction, according to the alignment of its molecules.

If unpolarised light is passed through two polaroid filters, the transmitted light intensity changes if one polaroid is turned relative to the other one. The filters are said to be crossed when the transmitted intensity is a minimum. At this position, the polarised light from the first filter cannot pass through the second filter, as the alignment of molecules in the second filter is at 90° to the alignment in the first filter. This is like passing rope waves through two letter boxes at right angles to each other, as shown in Figure 4.

Light is part of the spectrum of electromagnetic waves. The plane of polarisation of an electromagnetic wave is defined as the plane in which the electric field oscillates.

Polaroid sunglasses reduce the glare of light reflected by water or glass. The reflected light is polarised and the intensity is reduced when it passes through the polaroid sunglasses.



Activity 17 Polarisation

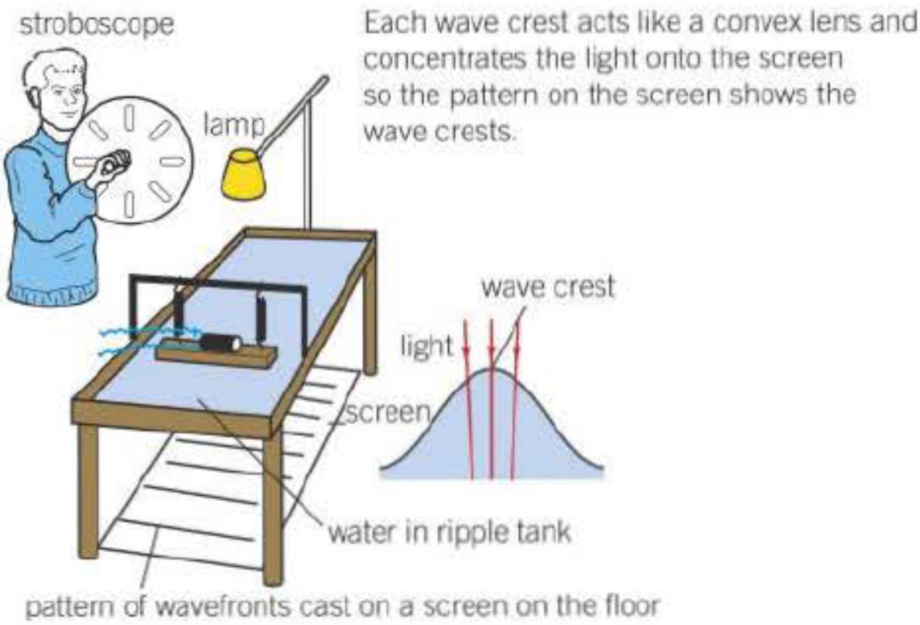
4 a What is meant by a polarised wave?

b A light source is observed through two pieces of polaroid which are initially aligned parallel to each other. Describe and explain what you would expect to observe when one of the polaroids is rotated through 360°.

Activity 18 The ripple tank

Wave properties such as reflection, refraction, and diffraction occur with many different types of waves. A **ripple tank** may be used to study these wave properties. The tank is a shallow transparent tray of water with sloping sides. The slopes prevent waves reflecting off the sides of tank. If they did reflect, it would be difficult to see the waves.

- The waves observed in a ripple tank are referred to as **wavefronts**, which are lines of constant phase (e.g., crests).
- The direction in which a wave travels is at right angles to the wavefront.



Reflection

Straight waves directed at a certain angle to a hard flat surface (the reflector) reflect off at the same angle, as shown in Figure 2. The angle between the reflected wavefront and the surface is the same as the angle between the incident wavefront and the surface. Therefore the direction of the reflected wave is at the same angle to the reflector as the direction of the incident wave. This effect is observed when a light ray is directed at a plane mirror. The angle between the incident ray and the mirror is equal to the angle between the reflected ray and the mirror.

Activity 18 The ripple tank

Refraction

When waves pass across a boundary at which the wave speed changes, the wavelength also changes. If the wavefronts approach at an angle to the boundary, they change direction as well as changing speed. This effect is known as **refraction**.

Figure 3 shows the refraction of water waves in a ripple tank when they pass across a boundary from deep to shallow water at an angle to the boundary. Because they move more slowly in the shallow water, the wavelength is smaller in the shallow water and therefore they change direction.

Refraction of light is observed when a light ray is directed into a glass block at an angle (i.e., not along the normal). The light ray changes direction when it crosses the glass boundary. This happens because light waves travel more slowly in glass than in air.

Diffraction

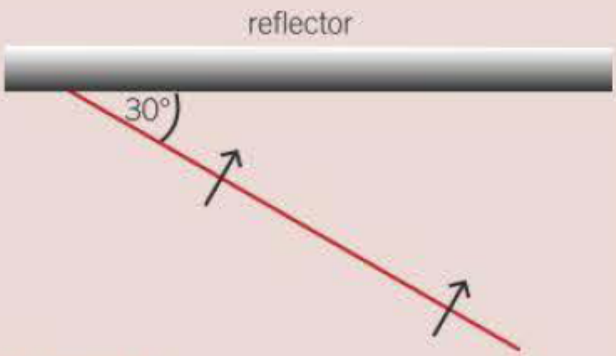
Diffraction occurs when waves spread out after passing through a gap or round an obstacle. The effect can be seen in a ripple tank when straight waves are directed at a gap, as shown in Figure 4.

- The narrower the gap, the more the waves spread out.
- The longer the wavelength, the more the waves spread out.

To explain why the waves are diffracted on passing through the gap, consider each point on a wavefront as a secondary emitter of wavelets. The wavelets from the points along a wavefront travel only in the direction in which the wave is travelling, not in the reverse direction, and they combine to form a new wavefront spreading beyond the gap.

Activity 18 The ripple tank

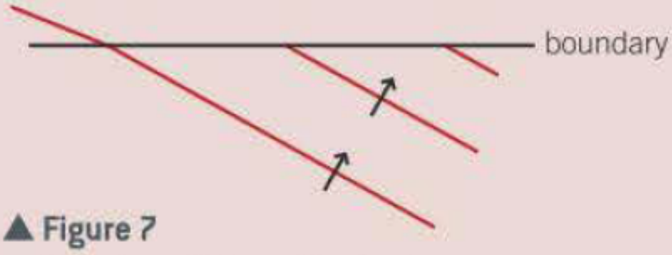
1 Copy and complete the diagram in Figure 6 by showing the wavefront after it has reflected from the straight reflector. Also show the direction of the reflected wavefront.



▲ **Figure 6**

2 A circular wave spreads out from a point P on a water surface, which is 0.50 m from a flat reflecting wall. The wave travels at a speed of 0.20 m s^{-1}. Sketch the arrangement and show the position of the wavefront **a** 2.5 s, **b** 4.0 s after the wavefront was produced at P.

3 Copy and complete the diagram in Figure 7 by showing the wavefronts after they passed across the boundary and have been refracted. Also show the direction of the refracted waves.



▲ **Figure 7**

4 Water waves are diffracted on passing through a gap. How is the amount of diffraction changed as a result of:

- **a** widening the gap without changing the wavelength
- **b** increasing the wavelength of the water waves without changing the gap width
- **c** increasing the wavelength of the water waves and reducing the gap width
- **d** widening the gap and increasing the wavelength of the waves?

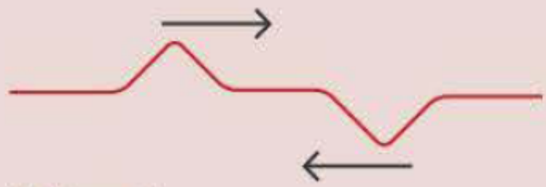
Activity 19 Superposition

When waves meet, they pass through each other. At the point where they meet, they combine for an instant before they move apart. This combining effect is known as **superposition**. Imagine a boat hit by two wave crests at the same time from different directions. Anyone on the boat would know it had been hit by a supercrest, the combined effect of two wave crests.

The principle of superposition states that when two waves meet, the total displacement at a point is equal to the sum of the individual displacements at that point.

- Where a crest meets a crest, a **supercrest** is created – the two waves reinforce each other.
- Where a trough meets a trough, a **supertrough** is created – the two waves reinforce each other.
- Where a crest meets a trough of the same amplitude, the resultant displacement is **zero**; the two waves cancel each other out. If they are not the same amplitude, the resultant is called a minimum.

1 Figure 5 shows two wave pulses on a rope travelling towards each other. Sketch a snapshot of the rope



▲ **Figure 5**

a when the two waves are passing through each other

b when the two waves have passed through each other.

2 How would you expect the interference pattern in Figure 3 to change if

a the two dippers are moved further apart

b the frequency of the waves produced by the dippers is reduced?

Activity 20 Stationary waves

When a guitar string is plucked, the sound produced depends on the way in which the string vibrates. If the string is plucked gently at its centre, a stationary wave of constant frequency is set up on the string. The sound produced therefore has a constant frequency. If the guitar string is plucked harshly, the string vibrates in a more complicated way and the note produced contains other frequencies, as well as the frequency produced when it is plucked gently.

As explained in Topic 4.4, a stationary wave is formed when two progressive waves pass through each other. This can be achieved on a string in tension by fixing both ends and making the middle part vibrate, so progressive waves travel towards each end, reflect at the ends, and then pass through each other.

The simplest stationary wave pattern on a string is shown in Figure 2. This is called the first harmonic of the string (sometimes referred to as its **fundamental mode of vibration**). It consists of a single loop that has a **node** (a point of no displacement) at either end. The string vibrates with maximum amplitude midway between the nodes. This position is referred to as an **antinode**. In effect, the string vibrates from side to side repeatedly. For this pattern to occur, the distance between the nodes at either end (i.e., the length of the string) must be equal to one half-wavelength of the waves on the string.

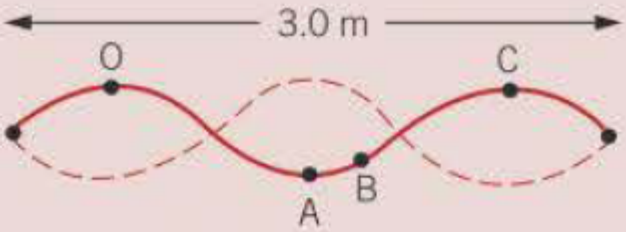
Stationary waves that vibrate freely do not transfer energy to their surroundings. The amplitude of vibration is zero at the nodes so there is no energy at the nodes. The amplitude of vibration is a maximum at the antinodes, so there is maximum energy at the antinodes. Because the nodes and antinodes are at fixed positions, no energy is transferred in a freely vibrating stationary wave pattern.

Activity 20 Stationary waves

1 a Sketch the stationary wave pattern seen on a rope when there is a node at either end and an antinode at its centre.

b If the rope in **a** is 4.0 m in length, calculate the wavelength of the waves on the rope.

2 The stationary wave pattern shown in Figure 5 is set up on a rope of length 3.0 m.



▲ **Figure 5**

a Calculate the wavelength of these waves.

b State the phase difference between the particle vibrating at O and the particle vibrating at

i A ii B iii C.

Activity 21 Refraction

The wave theory of light can be used to explain reflection and refraction of light. However, when we consider the effect of lenses or mirrors on the path of light, we usually prefer to draw diagrams using light rays and normals. Light rays represent the direction of travel of wavefronts. The **normal** is an imaginary line perpendicular to a boundary between two materials or a surface.

Refraction is the change of direction that occurs when light passes at an angle across a boundary between two transparent substances. Figure 2 shows the change of direction of a light ray when it enters and when it leaves a rectangular glass block in air. The light ray bends:

- towards the normal when it passes from air into glass
- away from the normal when it passes from glass into air.

No refraction takes place if the incident light ray is along the normal.

At a boundary between two transparent substances, the light ray bends:

- towards the normal if it passes into a more dense substance
- away from the normal if it passes into a less dense substance.

Use a ray box to direct a light ray into a rectangular glass block at different angles of incidence at the midpoint P of one of the longer sides, as shown in Figure 2. Note that the angle of incidence is the angle between the incident light ray and the normal at the point of incidence.

For each angle of incidence at P, mark the point Q where the light ray leaves the block. The angle of refraction is the angle between the normal at P and the line PQ. Measurements of the angles of incidence and refraction for different incident rays show that:

- the angle of refraction, r, at P is always less than the angle of incidence, i
- the ratio of $\frac{\sin i}{\sin r}$ is the same for each light ray. This is known as Snell's law. The ratio is referred to as the **refractive index**, n, of glass.

For a light ray travelling from air into a transparent substance,

$$\textbf{the refractive index of the substance, } n = \frac{\sin i}{\sin r}$$

Activity 21 Refraction

1 $\sqrt{x}$ **a** A light ray in air is directed into water from air. The refractive index of water is 1.33. Calculate the angle of refraction of the light ray in the water for an angle of incidence of

i 20° **ii** 40° **iii** 60°.

b A light ray in water is directed at the water surface at an angle of incidence of 40°.

i Calculate the angle of refraction of the light ray at this surface.

ii Sketch the path of the light ray showing the normal and the angles of incidence and refraction.

2 $\sqrt{x}$ A light ray is directed from air into a glass block of refractive index 1.5. Calculate:

a the angle of refraction at the point of incidence if the angle of incidence is **i** 30° **ii** 60°

b the angle of incidence if the angle of refraction at the point of incidence is **i** 35° **ii** 40°.

Activity 22 Constant acceleration (SUVAT)

1 The acceleration $a = \frac{(v - u)}{t}$, as explained in Topic 7.2, can be rearranged to give

$$v = u + at \qquad \textbf{(Equation 1)}$$

2 The displacement s = average velocity × time taken

Because the acceleration is uniform, average velocity = $\frac{(u + v)}{2}$

Combining this equation with $s = v \times t$ gives

$$s = \frac{(u + v)t}{2} \qquad \textbf{(Equation 2)}$$

3 By combining the two equations above to eliminate v, a further useful equation is produced.

To do this, substitute $u + at$ in place of v in equation 2. This gives

$$s = \frac{(u + (u + at))}{2}t = \frac{(u + u + at)t}{2} = \frac{(2ut + at^2)}{2}$$

$$s = ut + \tfrac{1}{2}at^2 \qquad \textbf{(Equation 3)}$$

4 A fourth useful equation is obtained by combining Equations 1 and 2 to eliminate t. This can be done by multiplying

$a = \frac{(v - u)}{t}$ and $s = \frac{(u + v)t}{2}$ together to give

$$as = \frac{(v - u)}{t} \times \frac{(u + v)t}{2}$$

This simplifies to become

$$as = \frac{(v - u)\ (v + u)}{2} = \frac{(v^2 - uv + uv - u^2)}{2} = \frac{(v^2 - u^2)}{2}$$

Therefore $2as = v^2 - u^2$ or

$$v^2 = u^2 + 2as \qquad \textbf{(Equation 4)}$$

The four equations, sometimes referred to as the *suvat* equations, are invaluable in any situation where the acceleration is constant.

Activity 22 Constant acceleration (SUVAT)

1 A vehicle accelerates uniformly along a straight road, increasing its velocity from 4.0 m s^{-1} to 30.0 m s^{-1} in 13 s. Calculate:

- **a** its acceleration
- **b** the displacement.

2 An aircraft lands on a runway at a velocity of 40 m s^{-1} and brakes to a halt in a distance of 860 m. Calculate:

- **a** the braking time
- **b** the deceleration of the aircraft.

3 A cyclist accelerates uniformly from rest to a speed of 6.0 m s^{-1} in 30 s then brakes at uniform deceleration to a halt in a distance of 24 m.

- **a** For the first part of the journey, calculate **i** the acceleration, **ii** the displacement.
- **b** For the second part of the journey, calculate **i** the deceleration, **ii** the time taken.
- **c** Sketch a velocity–time graph for this journey.
- **d** Use the graph to determine the average velocity for the journey.