A level Physics

Transition Pack

A level Physics transition booklet

The course we will study is OCR A level Physics A.

Any information about the course, including the specification and past papers can be found at the following link:

https://www.ocr.org.uk/qualifications/as-and-a-level/physics-a-h156-h556-from-2015/

The textbook we will mainly use is: **Oxford. A Level Physics for OCR. (ISBN:978-0-19-835218-1)**. There is a 645-page 2 year version or (perhaps more manageable) year 1 and year 2 versions.

<table>
<tr><th>Content Overview</th><th colspan="2">Assessment Overview</th></tr>
<tr><td rowspan="4">Content is split into six teaching modules:
• Module 1 – Development of practical skills in physics
• Module 2 – Foundations of physics
• Module 3 – Forces and motion
• Module 4 – Electrons, waves and photons
• Module 5 – Newtonian world and astrophysics
• Module 6 – Particles and medical physics
Component 01 assesses content from modules 1, 2, 3 and 5.
Component 02 assesses content from modules 1, 2, 4 and 6.
Component 03 assesses content from all modules (1 to 6).</td><td>Modelling physics (01)
100 marks
2 hours 15 minutes
written paper</td><td>37%
of total A level</td></tr>
<tr><td>Exploring physics (02)
100 marks
2 hours 15 minutes
written paper</td><td>37%
of total A level</td></tr>
<tr><td>Unified physics (03)
70 marks
1 hour 30 minutes
written paper</td><td>26%
of total A level</td></tr>
<tr><td>Practical Endorsement in physics
(04)
(non exam assessment)</td><td>Reported separately
(see Section 5g)</td></tr>
</table>

<u>Sections of this booklet:</u>

1) Introduction – this page
2) List of content
3) The foundations of physics chapter of the textbook – the first chapter we cover at the start of year 12. We will also cover experimental uncertainties with this, which is not seen in this chapter (but I feel should be). **Have a read through and attempt some of the question. Some are very easy, some are tougher.**
4) The equation booklet – you will be pleased to know this is provided in your exam (there is only about 5 equations you need to know by heart, and they are all easy). **Try to list the equations you recognize from GCSE and explain what they mean. Which GCSE level equations are missing and therefore are one's you will need to memorize?**
5) Short question memory exercises – **follow the instructions (look at questions with answers – cover up – try to answer without answers)**
6) Maths skills information and practice questions. – **Read through the information then attempt the questions (email MIE when you have tried them to be sent a link with the answers).**

List of content

The content listed below is in the specification but throughout the course. It gives a broad coverage of the world of physics, but we will endeavour to go beyond this list as there are always topics of interest and importance that all physicists should understand, even if they are not examined.

Module 1 – Development of practical skills in physics

1.1 Practical skills assessed in a written examination

1.2 Practical skills assessed in the practical endorsement

Module 2 – Foundations of physics

2.1 Physical quantities and units

2.2 Making measurements and analysing data

2.3 Nature of quantities Module

3 – Forces and motion

3.1 Motion

3.2 Forces in action

3.3 Work, energy and power

3.4 Materials

3.5 Newton’s laws of motion and momentum

Module 4 – Electrons, waves and photons

4.1 Charge and current

4.2 Energy, power and resistance

4.3 Electrical circuits

4.4 Waves

4.5 Quantum physics

Module 5 – Newtonian world and astrophysics

5.1 Thermal physics

5.2 Circular motion

5.3 Oscillations

5.4 Gravitational fields

5.5 Astrophysics and cosmology

Module 6 – Particles and medical physics

6.1 Capacitors

6.2 Electric fields

6.3 Electromagnetism

6.4 Nuclear and particle physics

6.5 Medical imaging

2 FOUNDATIONS OF PHYSICS

2.1 Quantities and units

Specification reference: 2.1.1, 2.1.2

Learning outcomes

Demonstrate knowledge, understanding, and application of:

→ units for physical quantities

→ SI base quantities and units, their symbols and prefixes.

▲ **Figure 1** *The correct use of units would have prevented the destruction of the Mars Climate Orbiter*

Measurements

Measurements are very important in physics. Not only must they be recorded accurately, they must also be communicated clearly. In 1998 NASA launched the Mars Climate Orbiter, a mission costing almost £195 million. When the probe arrived at Mars a few months later, it disintegrated in the planet's upper atmosphere instead of going into orbit. The disaster had a simple cause: one of NASA's teams worked in feet and pounds, whilst the other team worked in metres and kilograms. Each team assumed that the other was using the same units.

In A Level Physics, failure to use units correctly may not cost millions of pounds but it will cost you valuable marks in the examination.

Quantities

A physical **quantity** is a property of an object or of a phenomenon that can be measured. Some quantities are just numbers. For example, proton number, efficiency, and magnification are numbers. They have a numerical magnitude or size, but no units. Many other quantities consist of numbers *and* units. For example, length is a quantity that has units. It has many different units, including metres, inches, and miles. To avoid problems like the one NASA experienced with the Mars Climate Orbiter, scientists use a standard system of units called the *Système International d'Unités* (International System of Units), abbreviated to **SI**.

SI base units

SI is built around seven **base units**, six of which are shown in Table 1. The seventh unit, the unit for luminous intensity (the candela, cd), is not assessed in the A Level Physics course.

▼ **Table 1** *SI base units*

Quantity	Base unit	Unit symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampère	A
temperature	kelvin	K
amount of substance	mole	mol

Symbols

A unit symbol is written in lower case, for example, m rather than M for metres, unless the unit is named after a person. In that situation, its name still begins with a lower-case letter but its symbol has a capital letter. The unit of electric current is named after André-Marie Ampère, so its name is the ampère (often just amp) and its symbol is A.

Prefixes

SI uses prefixes to show multiples and fractions of units (Table 2). For example, km stands for kilometre. The **prefix** is the 'kilo', and the unit is the 'metre'.

Notice that, apart from k for kilo, the prefixes for multiples all have initial capitals. Similarly, the prefixes for fractions are all lower case (μ is the lower-case Greek letter mu).

Worked example: Using prefixes

a Convert 1.25 kA into A.

1.25 kA = 1.25×10^3 A (or 1250 A)

b Convert 234 μm into m.

234 μm = 234×10^{-6} m = 2.34×10^{-4} m

c Convert 0.567 s into ms.

There are 10^3 ms in 1 s. To change from seconds to milliseconds, you have to *multiply* by a factor of 10^3.

Therefore, 0.567 s = 0.567×10^3 = 567 ms

Summary questions

1 A student records the following figures in his notes: 60 cm and 40 ms.

a Name the two quantities being measured. *(2 marks)*

b Change these measurements into their base units. *(2 marks)*

2 a A collision between two molecules lasts for about 100 picoseconds. Write this time in seconds. *(1 mark)*

b A chemical bond is approximately 0.15 nanometres long. Write this length in metres. *(1 mark)*

c The Sun's core has a temperature of approximately 16 megakelvin. Write this temperature in kelvin. *(1 mark)*

3 Convert the following measurements to their base units. Write your answers in standard form.

a 200 pm; **b** 0.40 Mm; **c** 35 μs; **d** 0.25 mA; **e** 756 ns. *(5 marks)*

4 There are 86 400 s in a day. Alternatively you could say there are 86.4 ks in a day.

a The distance by train from London to Edinburgh is 5.34×10^5 m. What is this distance in km?

b The diameter of the Earth is 1.274×10^7 m. What is this diameter in Mm?

c The thickness of a human hair is about 7.5×10^{-5} m. What is this thickness in μm?

d The electric current in a nerve cell is about 1.4×10^{-7} A. What is this current in nA? *(4 marks)*

▼ **Table 2** *Prefixes for SI units*

Prefix name	Prefix symbol	Factor
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^9
mega	M	10^6
kilo	k	10^3
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Study tip

Standard form is used to display very small or very large numbers in a scientific way. For scientific notation it is ideally expressed in the form $n \times 10^m$, where $1 < n < 10$, and m is an integer.

Standard form

You can show small and large numbers in standard form.

For example, instead of writing 230 km or 230×10^3 m, we could express this distance as 2.3×10^5 m.

Write 45 ns (45×10^{-9} s) in standard form.

Study tip

Take care when you are writing prefixes and units. For example, ms means milliseconds, but Ms means megaseconds.

2.2 Derived units

Specification reference: 2.1.2

Learning outcomes

Demonstrate knowledge, understanding, and application of:

→ derived units of SI base units and the quantities that use them.

Beyond base units

The seven base units are used to measure the base quantities that they represent. However, there are many more quantities to measure than just mass, length, electric current, time, and the other three base quantities. For example, what are the units for speed and force? Quantities like these are called **derived quantities**. They use **derived units**, which can be worked out from the base units and the equations relating derived quantities to the base quantities. With derived units any quantity can be communicated.

Names and symbols

Derived units without special names

You already know some derived units. For example, the unit for speed is $\mathrm{m\,s^{-1}}$. It comes from the equation that links average speed with two base quantities – distance and time.

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

Since m is the unit for distance, s is the unit for time, and we are *dividing* m by s, the derived unit for speed is m/s, written $\mathrm{m\,s^{-1}}$ at A Level ($\mathrm{s^{-1}} = \frac{1}{\mathrm{s}}$). We write derived units like this because it is better for more complex units, such as the unit for specific heat capacity, $\mathrm{J\,kg^{-1}\,K^{-1}}$, which is much clearer than J/(kg K).

Table 1 shows some derived units without any special names.

▼ Table 1 *Some derived units*

Derived quantity	Derived unit
area	$\mathrm{m^2}$
volume	$\mathrm{m^3}$
acceleration	$\mathrm{m\,s^{-2}}$
density	$\mathrm{kg\,m^{-3}}$

Study tip

You can determine derived units from the equation for the derived quantity. For example, for density, you need the equation that links density, mass, and length:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

(where volume = length^3)

The derived unit for density is therefore the unit for mass (kg) divided by the unit for volume ($\mathrm{m^3}$): $\mathrm{kg\,m^{-3}}$.

▲ **Figure 1** *Speed is measured in $\mathrm{m\,s^{-1}}$, a derived unit in SI*

Derived units with special names

Some derived quantities are used so often that they have special names. SI has 22 derived units with special names and symbols, but you will not need to know them all for your physics course. Table 2 shows a small selection of these units.

▼ **Table 2** *Some named derived units*

Derived quantity	Unit name	Unit symbol	Unit expressed in other SI units
force	newton	N	$\mathrm{kg\,m\,s^{-2}}$
pressure	pascal	Pa	$\mathrm{N\,m^{-2}}$
energy or work done	joule	J	N m
power	watt	W	$\mathrm{J\,s^{-1}}$
electric potential difference	volt	V	$\mathrm{J\,C^{-1}}$
electric resistance	ohm	Ω	$\mathrm{V\,A^{-1}}$
electric charge	coulomb	C	A s
frequency	hertz	Hz	$\mathrm{s^{-1}}$

SI units can be combined to form a huge range of other derived units. You may be familiar with some of these already. For example, the moment of a force is measured in newton metres, N m.

Temperature

The SI base unit for temperature is the kelvin, K. In everyday life you are likely to use a different unit for temperature, a derived unit called the degree Celsius, °C. To convert from °C to K you add 273, so 20°C is 293 K and 100°C is 373 K.

A difference of 1°C is the same as a difference of 1 K, so temperature *differences* do not need conversion. For example, if you warm some water from 20°C to 100°C its temperature increases by 80°C, which is also 80 K.

1 Converting from K to °C is equally simple. Convert 298 K to °C.
2 The degree Fahrenheit, °F, is a non-SI unit for temperature. To convert from °F to °C you subtract 32, multiply by 5 then divide by 9. For example, 68°F = (68 − 32) × $\frac{5}{9}$ = 20°C. Deduce the temperature that has the same value, whether given in °F or in °C.

Summary questions

1 The unit of mass is the kg. Acceleration has the derived unit m s^{-2}. The force acting on an object can be determined using the equation force = mass × acceleration. Determine the derived unit for force in base units. *(2 marks)*

2 Use the equations given to determine the derived unit of each quantity in base units.

a force constant = $\frac{\text{force}}{\text{extension}}$

Extension is the change in length. Determine the derived unit for force constant. *(2 marks)*

b work done = force × distance moved in direction of force

Determine the derived unit for work done. *(2 marks)*

c pressure = $\frac{\text{force}}{\text{cross-sectional area}}$

Determine the derived unit for pressure. *(2 marks)*

3 State the difference between 1 N m, 1 nm, 1 mN and 1 MN. *(3 marks)*

4 In electrical work, it is useful to define a quantity known as *number density* of free electrons. Number density of free electrons is the number of electrons per unit volume. What is the unit for number density in base units? *(2 marks)*

2.3 Scalar and vector quantities

Specification reference: 2.3.1

Learning outcomes

Demonstrate knowledge, understanding, and application of:

→ scalar and vector quantities.

Going up

Flyboarding is a sport in which the rider stands on a board with a long hose attached that hangs into a lake. Water from the lake is forced through the hose and into jets under the board. The water rushes out of the jet nozzles, pushing the rider into the air. Skilled flyboarders can perform all sorts of aerial acrobatics, thanks to practice in judging scalar and vector quantities.

▲ **Figure 1** *Flyboarders can hover up to 15 m above the water*

Scalar quantities

A **scalar quantity** has magnitude (size) but no direction. For example, the *distance* between a flyboarder and the surface of the water is a scalar quantity, and so is his *mass* and the *time* he can stay in the air. Table 1 shows some examples of scalar quantities with their SI units.

Adding and subtracting scalar quantities

Scalar quantities can be added together or subtracted from one another in the usual way. For example, if your mass is 55 kg and you pick up a 5 kg bag, your new total mass is $(55 + 5) = 60\,\text{kg}$. If you sharpen a 16 cm pencil and remove 1 cm as you do so, the new length of the pencil is $(16 - 1) = 15\,\text{cm}$.

Scalar quantities must have the same units when you add or subtract them. If you time something in an experiment you cannot add together 1 *minute* and 30 *seconds* as $(1 + 30)$. Instead, you would convert the time from minutes into seconds and then add the times: $(60 + 30) = 90\,\text{s}$. Alternatively, you could work in minutes to get a time of $(1 + 0.5) = 1.5$ minutes.

▼ **Table 1** *Some scalar quantities and units*

Scalar quantity	SI unit
length	m
mass	kg
time	s
speed	m s^{-1}
temperature	K, °C
volume	m^3
energy	J
potential difference	V
power	W

Multiplying and dividing scalar quantities

Scalar quantities can also be multiplied together or divided by one another. However, in this case the units can be the same or different, unlike adding and subtracting. It is important that you work out the final units correctly.

Worked example: Lighter than air

A balloon is inflated with $6.1 \times 10^{-3}\,\text{m}^3$ of helium. Its mass increases by 0.98 g. Calculate the density of helium.

Step 1: The equation for density is

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Step 2: Consider the units of the equation.

You are dividing together two scalar quantities. The SI base unit for mass is the kg. Volume has the unit m^3. The mass must be converted into kg before substitution; mass $= 9.8 \times 10^{-4}\,\text{kg}$.

Step 3: Substitute the values into the equation and calculate the density.

$$\text{density} = \frac{9.8 \times 10^{-4}}{6.1 \times 10^{-3}} = 0.16\,\text{kg}\,\text{m}^{-3}$$

Vector quantities

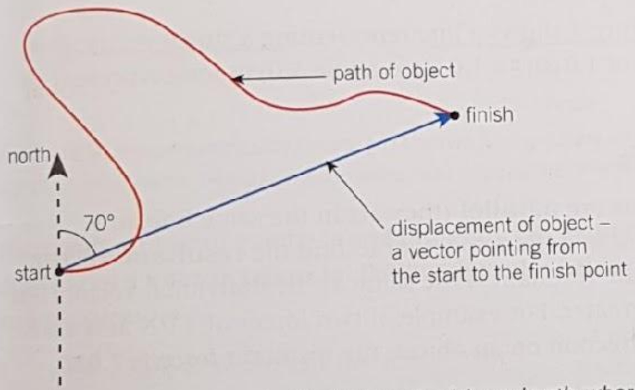
A **vector quantity** has magnitude *and* direction. For example, the weight of a flyboarder is a vector quantity, and so is the force from the rushing water from the jet nozzles. Table 2 shows some examples of vector quantities and their SI units.

▼ Table 2 *Some vector quantities and units*

Vector quantity	SI unit
displacement	m
velocity	$\text{m}\,\text{s}^{-1}$
acceleration	$\text{m}\,\text{s}^{-2}$
force	N ($\text{kg}\,\text{m}\,\text{s}^{-2}$)
momentum	$\text{kg}\,\text{m}\,\text{s}^{-1}$

Distance and displacement

Distance and displacement are both measured in m, but distance is a scalar quantity and displacement is a vector quantity. This is illustrated in Figure 2.



▲ Figure 2 *Distance travelled is the length of the red path, whereas the magnitude of the displacement is the length of the blue arrow and the direction of the displacement is 70° off due north*

Synoptic link

You find out more about vector quantities when studying motion, forces, and momentum in Chapters 3, 4, and 7 of this book.

Synoptic link

In Chapter 3, you will come across two important vector quantities – velocity and acceleration.

Summary questions

1 Explain what is wrong with the following calculation: (2 marks)
mass$_1$ = 150 g, mass$_2$ = 0.500 kg; total mass = 150 + 0.500 = 150.5 g

2 Compare and contrast distance and displacement. (2 marks)

3 You can calculate power by dividing energy by time. Explain whether power is a scalar or a vector quantity. (2 marks)

4 Figure 2 shows the path of a beetle that takes 20 s to travel from the start to the finish. The diagram is drawn to 1:1 scale. Determine:

a the distance travelled, using a length of string; (1 mark)

b the magnitude of the displacement; (1 mark)

c the average speed of the beetle. (2 marks)

5 Explain why the magnitude of the displacement of an object can never be greater than the distance travelled by the object. (1 mark)

2.4 Adding vectors

Specification reference: 2.3.1

Learning outcomes

Demonstrate knowledge, understanding, and application of:

→ addition of two vectors with scale drawings and with calculations.

▲ **Figure 1** *What effect will the flowing water have on the dog's progress across the river?*

Going against the flow

Many dogs love to jump into rivers to fetch sticks thrown for them. When a dog swims back to a point on the river bank, it has to swim against the current. The velocity of the flowing water and the velocity of the dog's paddling are vector quantities, so it is possible to work out the overall or **resultant** velocity of the dog by adding the two vectors together.

Vectors in one dimension

As you have already seen with displacement in Topic 2.3, a vector quantity is represented by a line with a single arrowhead:

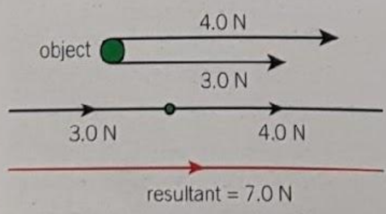
- the length of the line represents the magnitude of the vector, drawn to scale
- the direction in which the arrowhead points represents the direction of the vector.

For example, Figure 2 shows a line representing a single vector. It is drawn to a scale of $1.0\,\text{cm} \equiv 1.0\,\text{N}$, so a line 5.0 cm long represents a force of 5.0 N.

▲ **Figure 2** *Representing a vector quantity, in this example a force of 5.0 N*

Parallel vectors

Where two vectors are **parallel** (they act in the same line and direction), you just add them together to find the **resultant vector**. The direction of the resultant is the same as the individual vectors but its magnitude is greater. For example, if two forces of 3.0 N and 4.0 N act in the same direction on an object, the resultant force is 7.0 N.



▲ **Figure 3** *Two parallel forces acting on an object are shown at the top, with the corresponding vector diagrams below*

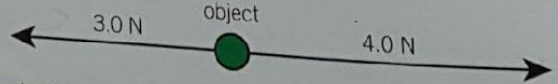
Antiparallel vectors

Where two vectors are **antiparallel** (they act in the same line but in opposite directions), you call one direction positive and the opposite direction negative (it does not matter which), and then add the vectors together to find the resultant. The magnitude and direction of the resultant will depend on the magnitude of the two vectors.

Worked example: Vectors in opposite directions

Two forces act in opposite directions on an object, as shown in Figure 4. Calculate the magnitude and direction of the resultant force.

Step 1: Assign positive and negative values to the vectors.
Assume that the positive direction is towards the right, so the two forces are −3.0 N and +4.0 N.



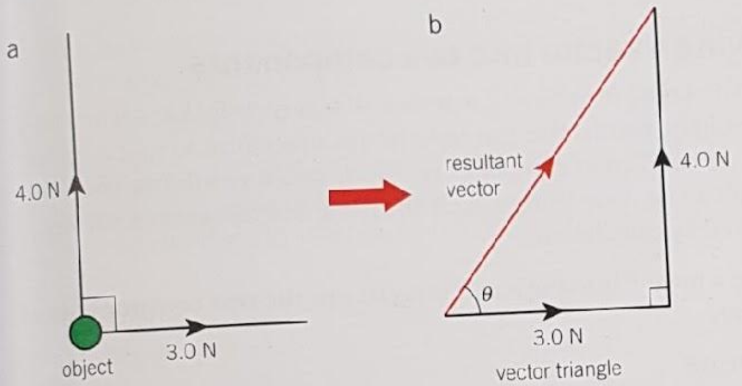
▲ **Figure 4** *Two forces acting in opposite directions*

Step 2: Calculate the resultant force.

resultant = −3.0 + 4.0 = +1.0 N towards the right

Two perpendicular vectors

Perpendicular vectors act at right angles to each other. Figure 5a represents two perpendicular forces of magnitudes 4.0 N and 3.0 N acting on an object.



▲ **Figure 5** *Two perpendicular forces: (a) the two forces acting on the object; (b) the vector triangle used to determine the resultant vector*

The resultant vector can be found either by calculation or by a scale drawing of a **vector triangle**. Follow the rules below when adding any two vectors.

1. Draw a line to represent the first vector.
2. Draw a line to represent the second vector, starting from the *end* of the first vector.
3. To find the resultant vector, join the start to the finish. You have created a vector triangle (Figure 5b).

The method can be used to determine the resultant vector for any two vectors – displacements, velocities, accelerations, and so on. The angle between the vectors need not be 90°; any triangle works.

In this case, since the angle is 90°, you can also determine the magnitude of the resultant force F using **Pythagoras' theorem**.

$$F^2 = 4.0^2 + 3.0^2$$

$$F = \sqrt{4.0^2 + 3.0^2} = \sqrt{25}$$

$$F = 5.0\,\text{N}$$

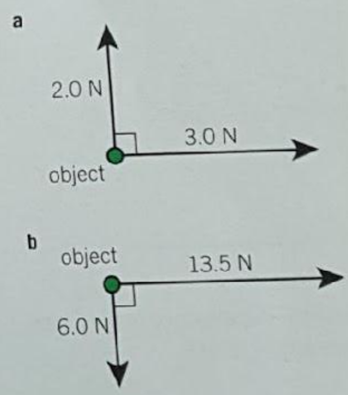
To find the direction of the resultant force, you can calculate the angle θ made with the 3.0 N force.

$$\tan\theta = \frac{\text{opp}}{\text{adj}} = \frac{4.0}{3.0} = 1.333$$

$$\theta = 53°$$

Summary questions

1. The steps on an escalator move upwards at $0.5\,\text{m}\,\text{s}^{-1}$. Calculate the resultant vertical velocity of a person:
   - **a** standing still on the escalator; *(1 mark)*
   - **b** walking upwards at $2.0\,\text{m}\,\text{s}^{-1}$; *(1 mark)*
   - **c** walking downwards at $1.0\,\text{m}\,\text{s}^{-1}$. *(1 mark)*
2. The diagrams in Figure 6 represent forces acting on an object. For each one, draw a vector triangle and therefore determine the magnitude and direction of the resultant force. *(10 marks)*



▲ **Figure 6**

3. A river flows due north at $0.90\,\text{m}\,\text{s}^{-1}$. A dog swims at $0.30\,\text{m}\,\text{s}^{-1}$. Calculate the magnitude and direction of the resultant velocity when the dog swims:
   - **a** due north; *(2 marks)*
   - **b** due south; *(2 marks)*
   - **c** due east. *(3 marks)*

2.5 Resolving vectors

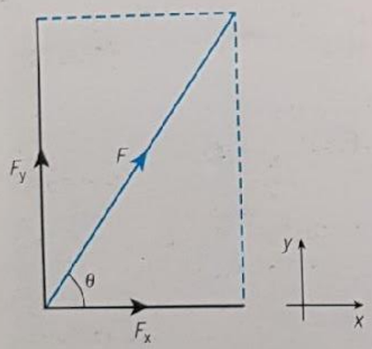
Specification reference: 2.3.1

Learning outcomes

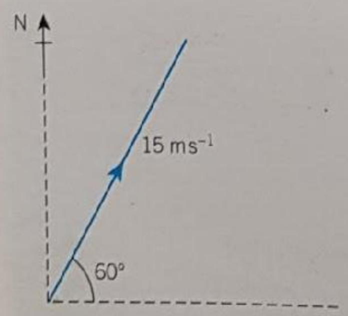
Demonstrate knowledge, understanding, and application of:

→ resolution of a vector into two perpendicular component vectors.

▲ Figure 1 *Pilots must compensate for the effect of crosswinds during take-off and landing*



▲ Figure 2 *Resolving a force F into components F_x and F_y*



▲ Figure 3

Crosswinds

The wind can be helpful to aircraft. A tailwind, blowing in the same direction as the aircraft is travelling, reduces the journey time and saves fuel. On the other hand, a headwind can increase the journey time and waste fuel. Crosswinds can blow an aircraft off course unless the pilot takes them into account. An understanding of vectors is helpful in situations like these.

Resolving a vector into two components

You already know how to add together two perpendicular vectors to find a resultant vector. You can reverse this procedure to split a vector into two perpendicular components. This is called **resolving the vector**. It can be done using a scale drawing, but more often vectors are resolved by calculation.

To resolve a force F into the x and y directions, the two **components** of the force are

- $F_x = F\cos\theta$
- $F_y = F\sin\theta$

where θ is the angle made with the x direction. These equations can be used with any vector in the place of x.

Worked example: A crosswind

At an airport, a horizontal wind is blowing at $15\,\mathrm{m\,s^{-1}}$ at an angle of 60° north of east (Figure 3). Calculate the components of the wind velocity in the north and east directions.

Step 1: Select the equations for resolving vectors.

- $v_x = v\cos\theta$
- $v_y = v\sin\theta$

Step 2: Substitute the values into the equations and calculate the components.

velocity component due east $= v_x = 15 \times \cos 60° = 7.5\,\mathrm{m\,s^{-1}}$

velocity component due north $= v_y = 15 \times \sin 60° = 13\,\mathrm{m\,s^{-1}}$

You can quickly check your answer using Pythagoras' theorem.

$$v^2 = v_x^2 + v_y^2 = 7.5^2 + 13^2 = 56.25 + 169$$
$$v = 15\,\mathrm{m\,s^{-1}}$$

Worked example: Going down

A freely falling object has a vertical acceleration of $9.81\,\mathrm{m\,s^{-2}}$. The object is placed on a smooth ramp that makes an angle of 30° to the horizontal (Figure 4). Calculate the component of the acceleration a down the ramp.

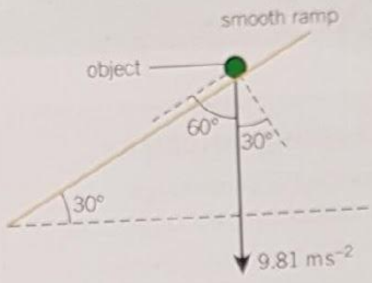
Step 1: Select the equation.

acceleration component down the ramp = $a\cos\theta$ where θ is the angle a makes to the slope.

Step 2: Substitute the values into the equations and calculate the component.

component = $9.81 \times \cos 60^\circ = 4.91\,\mathrm{m\,s^{-2}}$

You could have used $9.81 \times \sin 30^\circ$ instead. The answer will be the same because $\sin 30^\circ$ is the same as $\cos 60^\circ$.



▲ Figure 4

Study tip

Always check that your calculator is in the correct mode – in this case degrees – when you resolve vectors.

Summary questions

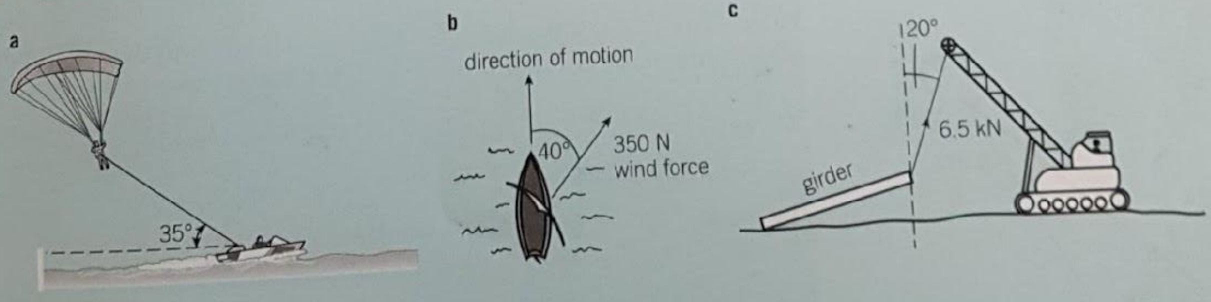
1 A force of 10 N acts on an object at an angle θ to the horizontal. Calculate the horizontal component of the force when $\theta = 0$, $\theta = 45^\circ$, and $\theta = 90^\circ$. Comment on your answers. *(4 marks)*

2 A parascender is attached by a rope to a boat travelling at a constant velocity (Figure 5a). The rope is angled at 35° to the surface of the sea, and the tension in the rope is 1650 N. Calculate the horizontal and vertical components of the tension in the rope. *(2 marks)*

3 A sailing boat is travelling north. It is moving because of a force due to the wind, which is 350 N blowing towards 40° east of north (Figure 5b). Calculate the components of the force from the wind:

a towards the north (the direction in which the boat is moving); *(1 mark)*

b towards the east (perpendicular to the direction in which the boat is moving). *(1 mark)*



▲ Figure 5

4 One end of a steel girder is lifted off the ground by a crane. The cable is at 20° from the vertical and the tension in the cable is 6.5 kN (Figure 5c). Calculate the vertical and horizontal components of this force. *(2 marks)*

2.6 More on vectors

Specification reference: 2.3.1

Learning outcomes

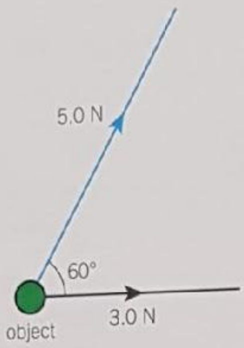
Demonstrate knowledge, understanding, and application of:

→ calculations involving vectors.

▲ **Figure 1** *Tugboats towing an oil platform*

Tugboats

A tugboat is a small but powerful boat that pushes or pulls larger vessels such as barges and tankers. Tugboats manoeuvre these large ships through crowded waterways and harbours. Larger, ocean-going tugboats can tow damaged ships to safety. Sometimes even the most powerful tugboats need to work in pairs or groups. Tugboat captains must understand the vectors involved so that the towed vessel travels in the right direction.



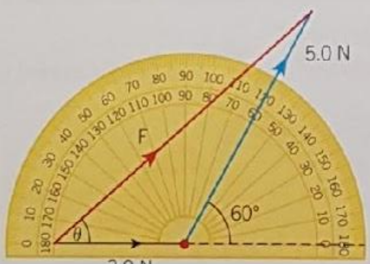
▲ **Figure 2** *Two non-perpendicular forces acting on an object*

Adding non-perpendicular vectors

There are several techniques you can use to add together two non-perpendicular vectors. They all rely on constructing a clear vector triangle. We will apply each of the techniques in turn to the following problem in order to demonstrate how to use them.

Two forces, of 5.0 N and 3.0 N, act on a single point at 60° to each other (Figure 2). What is the magnitude and direction of the resultant force?

Technique 1 – Scale diagram



▲ **Figure 3** *A vector triangle drawn to scale*

Choose an appropriate scale for the drawing of your vector triangle. Use the rules outlined in Topic 2.4 to construct your vector triangle (Figure 3).

Carefully measure the length of the resultant vector: it is 7.0 cm. With 1.0 cm representing 1.0 N in the diagram, the resultant force must equal 7.0 N. The angle made by the resultant and the 4.0 N force is 38°.

Technique 2 – Calculations using cosine and sine rules

Figure 4 shows a sketch of the vector triangle. The angles and magnitudes of the vectors are all shown. The resultant force is F.

You can use the cosine rule ($a^2 = b^2 + c^2 - 2bc\cos\theta$) to determine the magnitude of the resultant force.

$$F^2 = 3.0^2 + 5.0^2 - 2 \times 3.0 \times 5.0 \times \cos 120°$$

$$F = \sqrt{49} = 7.0\,\text{N}$$

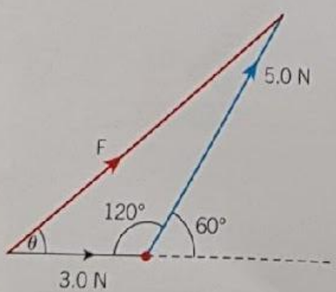
The angle θ can be found using the sine rule $\left(\dfrac{a}{\sin A} = \dfrac{b}{\sin B}\right)$.

$$\frac{5.0}{\sin\theta} = \frac{7.0}{\sin 120}$$

$$\sin\theta = \frac{5.0 \times \sin 120}{7.0} = 0.6186$$

$$\theta = 38°$$

The magnitude of the resultant force is 7.0 N at an angle of 38° relative to the 3.0 N force.



▲ **Figure 4** *A vector triangle with angles and forces shown*

Technique 3 – Calculations using vector resolution

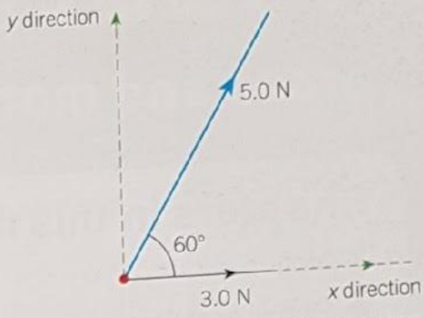
This technique relies on choosing convenient perpendicular axes. One of the vectors is resolved along each axis so that the magnitude of the resultant vector can be determined using Pythagoras' theorem (Figure 5).

total force in x direction $= 3.0 + 5.0\cos 60° = 5.5\,\mathrm{N}$

total force in y direction $= 5.0\sin 60° = 4.33\,\mathrm{N}$

resultant force $F = \sqrt{5.5^2 + 4.33^2} = 7.0\,\mathrm{N}$

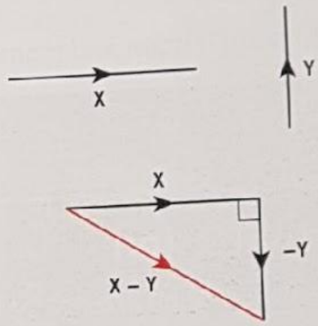
$$\theta = \tan^{-1}\left(\frac{4.33}{5.5}\right) = 38°$$



▲ **Figure 5** *Two non-perpendicular vectors shown as part of a right-angled triangle*

Subtracting vectors

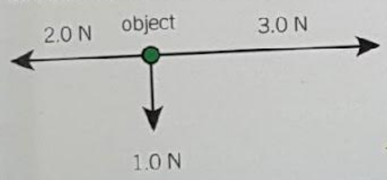
Two vectors are represented by **X** and **Y**. To subtract **Y** from **X**, you simply reverse the direction of **Y** and then add this new vector to **X** (Figure 6).



▲ **Figure 6** *Subtracting vectors*

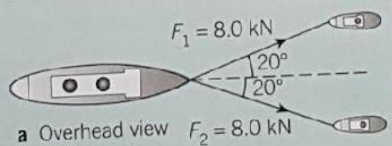
Summary questions

1 Three forces act on an object (Figure 7). Calculate the magnitude and direction of the resultant force. *(4 marks)*



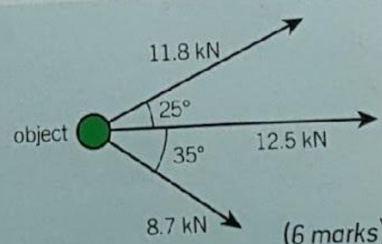
◀ **Figure 7**

2 Two tugboats are pulling a ship, each with a force of 8.0 kN, and with an angle of 40° between the cables (Figure 8). Calculate the magnitude and direction of the resultant force. *(4 marks)*



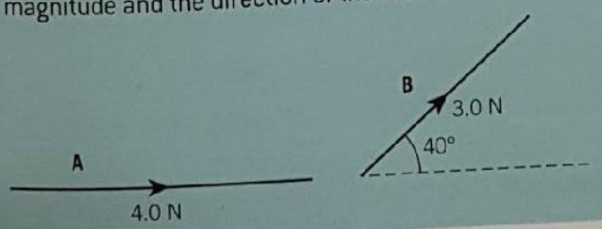
▲ **Figure 8**

3 Three tugboats are towing an object at sea. The forces and angles between the cables are shown in Figure 9. Calculate the magnitude and direction of the resultant force on the object. *(6 marks)*



▲ **Figure 9**

4 Figure 10 shows two vectors, A and B. Determine the magnitude and the direction of the resultant vector A – B. *(4 marks)*



◀ **Figure 10**

5c. Physics A data sheet

Data, Formulae and Relationships

The data, formulae and relationships in this data sheet will be printed for distribution with the examination papers.

Data

Values are given to three significant figures, except where more – or fewer – are useful.

Physical constants

acceleration of free fall	g	$9.81\ \mathrm{m\ s^{-2}}$
elementary charge	e	$1.60 \times 10^{-19}\ \mathrm{C}$
speed of light in a vacuum	c	$3.00 \times 10^{8}\ \mathrm{m\ s^{-1}}$
Planck constant	h	$6.63 \times 10^{-34}\ \mathrm{J\ s}$
Avogadro constant	N_A	$6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
molar gas constant	R	$8.31\ \mathrm{J\ mol^{-1}\ K^{-1}}$
Boltzmann constant	k	$1.38 \times 10^{-23}\ \mathrm{J\ K^{-1}}$
gravitational constant	G	$6.67 \times 10^{-11}\ \mathrm{N\ m^{2}\ kg^{-2}}$
permittivity of free space	ε_0	$8.85 \times 10^{-12}\ \mathrm{C^{2}\ N^{-1}\ m^{-2}\ (F\ m^{-1})}$
electron rest mass	m_e	$9.11 \times 10^{-31}\ \mathrm{kg}$
proton rest mass	m_p	$1.673 \times 10^{-27}\ \mathrm{kg}$
neutron rest mass	m_n	$1.675 \times 10^{-27}\ \mathrm{kg}$
alpha particle rest mass	m_α	$6.646 \times 10^{-27}\ \mathrm{kg}$
Stefan constant	σ	$5.67 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$

Quarks

up quark	charge = $+\frac{2}{3}e$
down quark	charge = $-\frac{1}{3}e$
strange quark	charge = $-\frac{1}{3}e$

Conversion factors

unified atomic mass unit	$1\ \text{u} = 1.661 \times 10^{-27}$ kg
electronvolt	$1\ \text{eV} = 1.60 \times 10^{-19}$ J
day	$1\ \text{day} = 8.64 \times 10^{4}$ s
year	$1\ \text{year} \approx 3.16 \times 10^{7}$ s
light year	$1\ \text{light year} \approx 9.5 \times 10^{15}$ m
parsec	$1\ \text{parsec} \approx 3.1 \times 10^{16}$ m

Mathematical equations

arc length = $r\theta$

circumference of circle = $2\pi r$

area of circle = πr^2

curved surface area of cylinder = $2\pi rh$

surface area of sphere = $4\pi r^2$

area of trapezium = $\frac{1}{2}(a+b)h$

volume of cylinder = $\pi r^2 h$

volume of sphere = $\frac{4}{3}\pi r^3$

Pythagoras' theorem: $a^2 = b^2 + c^2$

cosine rule: $a^2 = b^2 + c^2 - 2bc\cos A$

sine rule: $\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$

$\sin\theta \approx \tan\theta \approx \theta$ and $\cos\theta \approx 1$ for small angles

$\log(AB) = \log(A) + \log(B)$ (Note: $\lg = \log_{10}$ and $\ln = \log_e$)

$\log\left(\frac{A}{B}\right) = \log(A) - \log(B)$

$\log(x^n) = n\log(x)$

$\ln(e^{kx}) = kx$

Formulae and relationships

Module 2 – Foundations of physics	
vectors	$F_x = F\cos\theta$ $F_y = F\sin\theta$

Module 3 – Forces and motion	
uniformly accelerated motion	$v = u + at$ $s = \frac{1}{2}(u+v)t$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
force	$F = \frac{\Delta p}{\Delta t}$ $p = mv$
turning effects	$moment = Fx$ $torque = Fd$
density	$p = \frac{m}{V}$
pressure	$p = \frac{F}{A}$ $p = h\rho g$
work, energy and power	$W = Fx\cos\theta$ $\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times 100\%$ $P = \frac{W}{t}$ $P = Fv$
springs and materials	$F = kx$ $E = \frac{1}{2}Fx;\ E = \frac{1}{2}kx^2$ $\sigma = \frac{F}{A}$ $\varepsilon = \frac{x}{L}$ $E = \frac{\sigma}{\varepsilon}$

Module 4 – Electrons, waves and photons	
charge	$\Delta Q = I\Delta t$
current	$I = Anev$
work done	$W = VQ$; $W = \mathcal{E}Q$; $W = VIt$
resistance and resistors	$R = \dfrac{\rho L}{A}$ $R = R_1 + R_2 + \dots$ $\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dots$
power	$P = VI$, $P = I^2R$ and $P = \dfrac{V^2}{R}$
internal resistance	$\mathcal{E} = I(R + r)$; $\mathcal{E} = V + Ir$
potential divider	$V_{out} = \dfrac{R_2}{R_1 + R_2} \times V_{in}$ $\dfrac{V_1}{V_2} = \dfrac{R_1}{R_2}$
waves	$v = f\lambda$ $f = \dfrac{1}{T}$ $I = \dfrac{P}{A}$ $\lambda = \dfrac{ax}{D}$
refraction	$n = \dfrac{c}{v}$ $n \sin\theta = \text{constant}$ $\sin C = \dfrac{1}{n}$
quantum physics	$E = hf \quad E = \dfrac{hc}{\lambda}$ $hf = \phi + KE_{max}$ $\lambda = \dfrac{h}{p}$

Module 5 – Newtonian world and astrophysics	
thermal physics	$E = mc\Delta\theta$ $E = mL$
ideal gases	$pV = NkT$; $pV = nRT$ $pV = \frac{1}{3}Nm\overline{c^2}$ $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ $E = \frac{3}{2}kT$
circular motion	$\omega = \frac{2\pi}{T}$; $\omega = 2\pi f$ $v = \omega r$ $a = \frac{v^2}{r}$; $a = \omega^2 r$ $F = \frac{mv^2}{r}$; $F = m\omega^2 r$
oscillations	$\omega = \frac{2\pi}{T}$; $\omega = 2\pi f$ $a = -\omega^2 x$ $x = A\cos\omega t$; $x = A\sin\omega t$ $v = \pm\omega\sqrt{A^2 - x^2}$
gravitational field	$g = \frac{F}{m}$ $F = -\frac{GMm}{r^2}$ $g = -\frac{GM}{r^2}$ $T^2 = \left(\frac{4\pi^2}{GM}\right)r^3$ $V_g = -\frac{GM}{r}$ energy $= -\frac{GMm}{r}$
astrophysics	$hf = \Delta E$; $\frac{hc}{\lambda} = \Delta E$ $d\sin\theta = n\lambda$ $\lambda_{max} \propto \frac{1}{T}$ $L = 4\pi r^2\ \sigma T^4$

cosmology

$$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$$

$$p = \frac{1}{d}$$

$$v = H_0 d$$

$$t = H_0^{-1}$$

Module 6 - Particles and medical physics

capacitance and capacitors

$$C = \frac{Q}{V}$$

$$C = \frac{\varepsilon_0 A}{d}$$

$$C = 4\pi\varepsilon_0 R$$

$$C = C_1 + C_2 + \dots$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots.$$

$$W = \tfrac{1}{2}QV; \;\; W = \tfrac{1}{2}\frac{Q^2}{C}; \;\; W = \tfrac{1}{2}V^2C$$

$$\tau = CR$$

$$x = x_0 e^{-\frac{t}{CR}}$$

$$x = x_0(1 - e^{-\frac{t}{CR}})$$

electric field

$$E = \frac{F}{Q}$$

$$F = \frac{Qq}{4\pi\varepsilon_0 r^2}$$

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

$$E = \frac{V}{d}$$

$$V = \frac{Q}{4\pi\varepsilon_0 r}$$

$$\text{energy} = \frac{Qq}{4\pi\varepsilon_0 r}$$

magnetic field

$$F = BIL\sin\theta$$

$$F = BQv$$

electromagnetism	$\phi = BA\cos\theta$ $\varepsilon = -\dfrac{\Delta(N\phi)}{\Delta t}$ $\dfrac{n_s}{n_p} = \dfrac{V_s}{V_p} = \dfrac{I_p}{I_s}$
radius of nucleus	$R = r_0 A^{\frac{1}{3}}$
radioactivity	$A = \lambda N; \dfrac{\Delta N}{\Delta t} = -\lambda N$ $\lambda t_{\frac{1}{2}} = \ln(2)$ $A = A_0 e^{-\lambda t}$ $N = N_0 e^{-\lambda t}$
Einstein's mass-energy equation	$\Delta E = \Delta mc^2$
attenuation of X-rays	$I = I_0 e^{-\mu x}$
ultrasound	$Z = \rho c$ $\dfrac{I_r}{I_0} = \dfrac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$ $\dfrac{\Delta f}{f} = \dfrac{2v\cos\theta}{c}$

Retrieval questions

You need to be confident about the definitions of terms that describe measurements and results in A Level 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.

Practical science key terms

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

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 are the equations to resolve a force, F, into two perpendicular components, F_x and F_y?	$F_x = F\cos\theta$ $F_y = F\sin\theta$
What is the difference between distance and displacement?	distance is a scalar quantity 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 displacement is the area under the graph
Write the equation for acceleration in algebraic form	$a = \frac{\Delta v}{\Delta t}$
What do the letters *suvat* stand for in the equations of motion?	s = displacement, u = initial velocity, v = final velocity, a = acceleration, t = time taken
Write the four *suvat* equations.	$v = u + at$ $s = ut + \frac{1}{2}at^2$ $s = \frac{1}{2}(u+v)t$ $v^2 = u^2 + 2as$
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

Matter and 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.

What is an atom made up of?	a positively charged nucleus containing protons and neutrons, surrounded by electrons
Define a *nucleon*	a proton or a neutron in the nucleus
What are the absolute charges of protons, neutrons, and electrons?	$+\ 1.60\times10^{-19}$, 0, and $-\ 1.60\times10^{-19}$ coulombs (C) respectively
What are the relative charges of protons, neutrons, and electrons?	1, 0, and − 1 respectively (charge relative to proton)
What is the mass, in kilograms, of a proton, a neutron, and an electron?	1.67×10^{-27}, 1.67×10^{-27}, and 9.11×10^{-31} kg respectively
What are the relative masses of protons, neutrons, and electrons?	1, 1, and 0.0005 respectively (mass relative to proton)
What is the atomic number of an element?	the number of protons
Define an isotope	isotopes are atoms with the same number of protons and different numbers of neutrons
Write what *A*, *Z* and X stand for in isotope notation ($^{A}_{Z}X$)?	*A*: the number of nucleons (protons + neutrons) *Z*: the number of protons X: the chemical symbol
Which term is used for each type of nucleus?	nuclide
How do you calculate specific charge?	charge divided by mass (for a charged particle)
What is the specific charge of a proton and an electron?	9.58×10^{7} and 1.76×10^{11} C kg^{-1} respectively
Name the force that holds nuclei together	strong nuclear force
What is the range of the strong nuclear force?	from 0.5 to 3–4 femtometres (fm)
Name the three kinds of radiation	alpha, beta, and gamma
What particle is released in alpha radiation?	an alpha particle, which comprises two protons and two neutrons
Write the symbol of an alpha particle	$^{4}_{2}\alpha$
What particle is released in beta radiation?	a fast-moving electron (a beta particle)
Write the symbol for a beta particle	$^{0}_{-1}\beta$
Define *gamma radiation*	electromagnetic radiation emitted by an unstable nucleus
What particles make up everything in the universe?	matter and antimatter
Name the antimatter particles for electrons, protons, neutrons, and neutrinos	positron, antiproton, antineutron, and antineutrino respectively
What happens when corresponding matter and antimatter particles meet?	they annihilate (destroy each other)
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	$\text{wavelength } (\lambda) = \dfrac{\text{speed of light } (c)}{\text{frequency } (f)}$
Define a *photon*	a packet of electromagnetic waves
What is the speed of light?	3.00×10^{8} m s^{-1}
Write the equation for calculating photon energy	photon energy (*E*) = Planck constant (*h*) × frequency (*f*)
Name the four fundamental interactions	gravity, electromagnetic, weak nuclear, strong nuclear

Oxford **A Level Sciences**

Physics

GCSE → A Level transition student worksheet

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:

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

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

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	period^{-1}	s^{-1}	Hz, hertz
volume	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:

9.42×10^{-5} 1.56×10^{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 5.90×10^2

Practice questions

2 Give these measurements to 2 significant figures:

a 19.47 m   **b** 21.0 s   **c** 1.673×10^{-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 = 1.3×10^4 km.
- The distance to the Andromeda galaxy is 2 200 000 light years = 2.2 × 1 000 000 ly = 2.2×10^6 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 6.8×10^9 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 = 1.6×10^{-19} C.
- The mass of a neutron = $0.016\,75 \times 10^{-25}$ kg = 1.675×10^{-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** 160×10^{-17} m **c** 0.01×10^{-6} J **d** 0.005×10^6 m **e** 0.00062×10^3 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 = 1×10^{-5} m

c a wavelength of blue light = 4.7×10^{-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 3.0×10^8 m s^{-1}. Use the equation $v = f\lambda$ (where λ is wavelength) to calculate the frequency of:

a ultraviolet, wavelength 3.0×10^{-7} m

b radio waves, wavelength 1000 m

c X-rays, wavelength 1.0×10^{-10} m.

3 Resolving vectors

3.1 Vectors and scalars

Vectors have a magnitude (size) and a direction. Directions can be given as points of the compass, angles or words such as forwards, left or right. For example, 30 mph east and 50 km/h north-west are velocities.

Scalars have a magnitude, but no direction. For example, 10 m/s is a speed.

Practice questions

1 State whether each of these terms is a vector quantity or a scalar quantity: density, temperature, electrical resistance, energy, field strength, force, friction, frequency, mass, momentum, power, voltage, volume, weight, work done.

2 For the following data, state whether each is a vector or a scalar: 3 ms^{-1}, +20 ms^{-1}, 100 m NE, 50 km, −5 cm, 10 km S 30° W, 3×10^8 ms^{-1} upwards, 273 °C, 50 kg, 3 A.

3.2 Drawing vectors

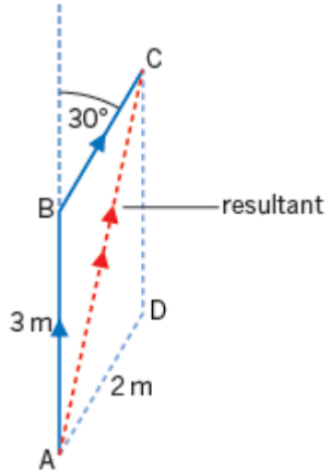
Vectors are shown on drawings by a straight arrow. The arrow starts from the point where the vector is acting and shows its direction. The length of the vector represents the magnitude.

When you add vectors, for example two velocities or three forces, you must take the direction into account.

The combined effect of the vectors is called the resultant.

This diagram shows that walking 3 m from A to B and then turning through 30° and walking 2 m to C has the same effect as walking directly from A to C. AC is the resultant vector, denoted by the double arrowhead.

A careful drawing of a scale diagram allows us to measure these. Notice that if the vectors are combined by drawing them in the opposite order, AD and DC, these are the other two sides of the parallelogram and give the same resultant.



Practice questions

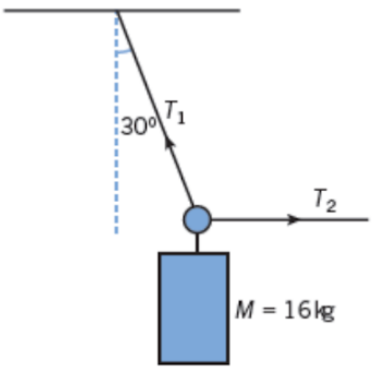
3 Two tractors are pulling a log across a field. Tractor 1 is pulling north with force 1 = 5 kN and tractor 2 is pulling east with force 2 = 12 kN. By scale drawing, determine the resultant force.

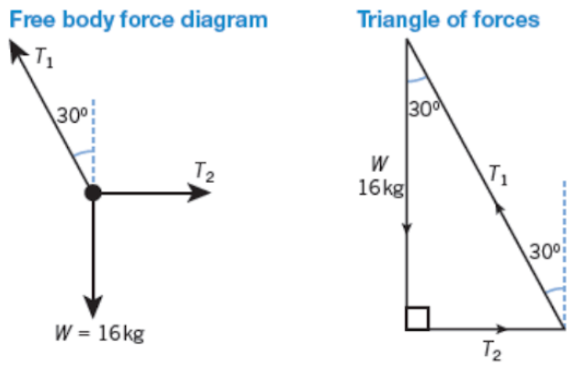
3.3 Free body force diagrams

To combine forces, you can draw a similar diagram to the one above, where the lengths of the sides represent the magnitude of the force (e.g., 30 N and 20 N). The third side of the triangle shows us the magnitude and direction of the resultant force.

When solving problems, start by drawing a free body force diagram. The object is a small dot and the forces are shown as arrows that start on the dot and are drawn in the direction of the force. They don't have to be to scale, but it helps if the larger forces are shown to be larger. Look at this example.

A 16 kg mass is suspended from a hook in the ceiling and pulled to one side with a rope, as shown on the right. Sketch a free body force diagram for the mass and draw a triangle of forces.





Notice that each force starts from where the previous one ended and they join up to form a triangle with no resultant because the mass is in equilibrium (balanced).

Practice questions

4 Sketch a free body force diagram for the lamp (**Figure 1**, below) and draw a triangle of forces.

5 There are three forces on the jib of a tower crane (**Figure 2**, below). The tension in the cable T, the weight W, and a third force P acting at X.

The crane is in equilibrium. Sketch the triangle of forces.

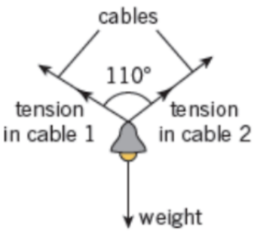


Figure 1

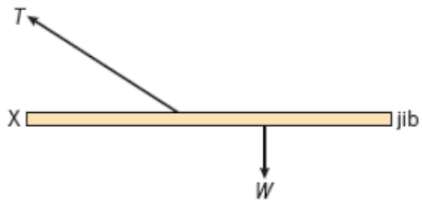


Figure 2

3.4 Calculating resultants

When two forces are acting at right angles, the resultant can be calculated using Pythagoras's theorem and the trig functions: sine, cosine, and tangent.

For a right-angled triangle as shown:

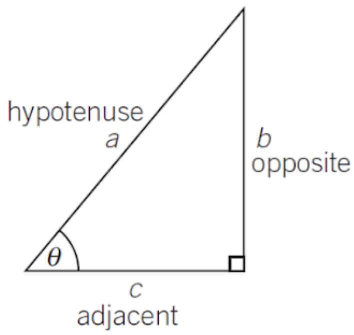
$h^2 = o^2 + a^2$

$\sin\theta = \dfrac{o}{h}$

$\cos\theta = \dfrac{a}{h}$

$\tan\theta = \dfrac{o}{a}$

(soh-cah-toa).



Practice questions

6 **Figure 3** shows three forces in equilibrium.
Draw a triangle of forces to find T and α.

7 Find the resultant force for the following pairs of forces at right angles to each other:

a 3.0 N and 4.0 N   **b** 5.0 N and 12.0 N

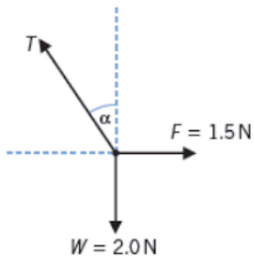


Figure 3

4 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

4.1 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

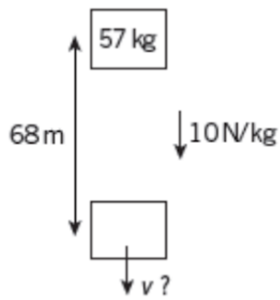
1 The potential difference across a resistor is 12 V and the current through it is 0.25 A. Calculate its resistance.

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

4.2 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:

$$\frac{mgh}{0.5m} = \frac{0.5mv^2}{0.5m}$$

$2\,g\,h = v^2$

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

Step 4: Substitute into the equation:

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

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

Practice questions

3 Calculate the specific latent heat of fusion for water from this data:
4.03×10^4 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.

5 Work done, power, and efficiency

5.1 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.

5.2 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 Δh 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.

5.3 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.