Volume

One

ST MARY'S SCIENCE DEPARTMENT:

PHYSICS

A LEVEL PHYSICS **YEAR 1**

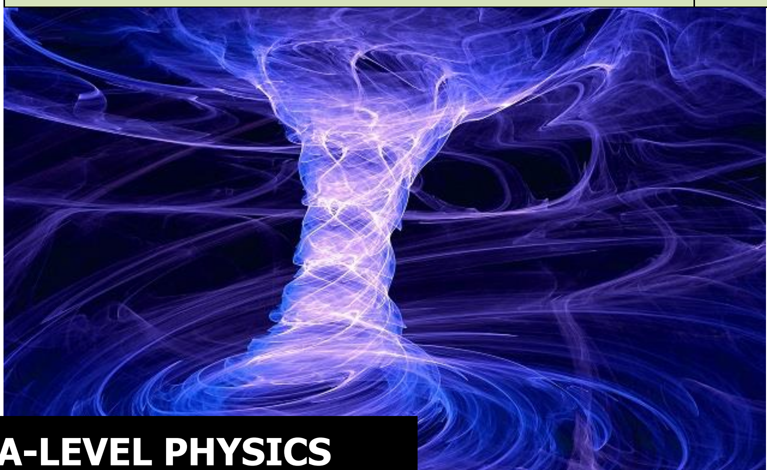
STUDENT CLASS BOOK

MECHANICS AND MATERIALS

FORCES AND ENERGY

VOLUME **ONE**

NAME	
PHYSICS CLASS	
MODULE TEACHER	
ALPS GRADE	



A-LEVEL PHYSICS

TOPIC 4

CLASS WORKBOOK 1

THIS MUST BE BROUGHT TO ALL PHYSICS LESSONS.

Contents

OVERVIEW

Vectors and their treatment are introduced followed by development of the student's knowledge and understanding of forces, energy and momentum.

The section continues with a study of materials considered in terms of their bulk properties and tensile strength.

IMPORTANT NOTE

This book, along with the preparatory reading notes and independent work, must be brought to all Physics lessons with the appropriate teacher.

This book may be used as a learning resource in lessons, you are not fully equipped to learn if this is not used in lesson.

This book may also be used as a revision resource for intervention, internal assessments and external assessments.

Please keep this in your student file.

There are several activities in this book which may not be covered in lessons.

It is advised that students complete these activities outside of lessons as revision aides.

Definition List

Definitions you must learn for this module.

Key Word	Symbol	Definition
Acceleration	**a**	Change of velocity per unit time.
Acceleration of free fall	**g**	Acceleration of an object acted on only by the force of gravity.
Centre of mass		The centre of mass of a body is the point through which a single force on the body has no turning effect.
Couple		A pair of equal and opposite forces acting on a body but not along the same line.
Displacement	**s**	The distance travelled in a given direction.
Drag force	**F**	The force of fluid resistance on an object moving through the fluid.
Efficiency		The ratio of useful energy transferred by a machine or a device to the energy supplied to it.
Effort		The force applied to a machine to make it move.
Energy	**E**	The capacity to do work.
Equilibrium		State of an object when at rest or in uniform motion.
Force	**F**	Any interaction that can change the velocity of an object.
Free Body Force Diagram		A diagram of an object showing only the forces acting on the object.
Friction	**F**	A force opposing the motion of a surface that moves or tries to move across another surface.
Inertia		The resistance of an object to change its motion.
Load		The force to be overcome by a machine when it shifts or raises an object.
Mass	**m**	A measure of inertia or resistance to change of motion of an object.
Moment of a force about a point	**M**	The force x perpendicular distance from the line of action of the force to a point.
Momentum	**p**	The mass x velocity.

Motive force	**F**	The force that drives a vehicle.
Newton's 1st Law of Motion		An object remains at rest or in uniform motion unless acted on by a resultant force.
Newton's 2nd Law of Motion		The rate of change of momentum of an object is proportional to the resultant force.
Power	**P**	The rate of transfer of energy.
Principle of conservation of energy		Energy cannot be created or destroyed.
Projectile		A projected object in motion acted on only by the force of gravity.
Scalar		A physical quantity with magnitude only.
Speed	**s**	The change of distance per unit time.
Terminal speed		The maximum speed reached by an object when the drag force on it is equal and opposite to the force causing the motion of the object.
Useful energy		Energy transferred to where it is wanted when it is wanted.
Vector		A physical quantity with magnitude and direction.
Velocity	**v**	The change of displacement per unit time.
Weight	**W**	The force of gravity acting on an object.
Work,	**W**	The force x distance moved in the direction of the force.

IMPORTANT NOTE
These definitions must be memorised by students.

You will be tested on your knowledge of these definitions.

Equations

The equations below are used in this module.

Quantity/Concept	Equation(s)
Horizontal Component of a Force	F_H = F cos (angle from horizontal) **This is not given in your examination.**
Vertical Component of a Force	F_V = F sin (angle from horizontal) **This is not given in your examination.**
Moment of a Force	M = F x d Where d is the perpendicular distance from the point to the line of action of the force
Moment of a Couple	M = F x d Where F is the size of one of the force and d is the perpendicular distance between the lines of action of the forces. **This is not given in your examination.**
Weight	W = m x g
Velocity	$v = \frac{\Delta s}{\Delta t}$
Acceleration	$a = \frac{\Delta v}{\Delta t}$
Distance Travelled	d = v x t
Equations for Uniform Acceleration	$v = u + at$ $s = \frac{(u + v)}{2} t$ $s = ut + \frac{at^2}{2}$ $v^2 = u^2 + 2as$
Projectile Motion	$v = gt$ $v^2 = 2gs$ $s = ½ gt^2$ $s = vt /2$ **These are not given in your examination.**

IMPORTANT NOTE
These equations must be memorised by students.

You will be tested on these equations.

The Language of Measurement

The following subject specific vocabulary provides definitions of key terms used in the A-level Science specifications.

Accuracy
A measurement result is considered accurate if it is judged to be close to the true value.

Calibration
Marking a scale on a measuring instrument.
This involves establishing the relationship between indications of a measuring instrument and standard or reference quantity values, which must be applied.
For example, placing a thermometer in melting ice to see whether it reads 0 °C, to check if it has been calibrated correctly.

Data
Information, either qualitative or quantitative, that has been collected.

Errors
See also uncertainties.

Measurement error
The difference between a measured value and the true value.
anomalies
These are values in a set of results which are judged not to be part of the variation caused by random uncertainty.

Random error
These cause readings to be spread about the true value, due to results varying in an unpredictable way from one measurement to the next.
Random errors are present when any measurement is made, and cannot be corrected. The effect of random errors can be reduced by making more measurements and calculating a new mean.

Systematic error
These cause readings to differ from the true value by a consistent amount each time a measurement is made.
Sources of systematic error can include the environment, methods of observation or instruments used.
Systematic errors cannot be dealt with by simple repeats. If a systematic error is suspected, the data collection should be repeated using a different technique or a different set of equipment, and the results compared.

Zero error
Any indication that a measuring system gives a false reading when the true value of a measured quantity is zero, e.g. the needle on an ammeter failing to return to zero when no current flows.
A zero error may result in a systematic uncertainty.

Evidence
Data which has been shown to be valid.

Fair test
A fair test is one in which only the independent variable has been allowed to affect the dependent variable.

Hypothesis
A proposal intended to explain certain facts or observations.

Interval
The quantity between readings, e.g. a set of 11 readings equally spaced over a distance of 1 metre would give an interval of 10 centimetres.

Precision
Precise measurements are ones in which there is very little spread about the mean value.
Precision depends only on the extent of random errors – it gives no indication of how close results are to the true value.

Prediction
A prediction is a statement suggesting what will happen in the future, based on observation, experience or a hypothesis.

Range
The maximum and minimum values of the independent or dependent variables; important in ensuring that any pattern is detected.
For example, a range of distances may be quoted as either:
'From 10 cm to 50 cm'
or
'From 50 cm to 10 cm'

Repeatable
A measurement is repeatable if the original experimenter repeats the investigation using same method and equipment and obtains the same results.

Reproducible
A measurement is reproducible if the investigation is repeated by another person, or by using different equipment or techniques, and the same results are obtained.

Resolution
This is the smallest change in the quantity being measured (input) of a measuring instrument that gives a perceptible change in the reading.

Sketch graph
A line graph, not necessarily on a grid, that shows the general shape of the relationship between two variables. It will not have any points plotted and although the axes should be labelled they may not be scaled.

True value
This is the value that would be obtained in an ideal measurement.

Uncertainty
The interval within which the true value can be expected to lie, with a given level of confidence or probability, e.g. "the temperature is 20 °C ± 2 °C, at a level of confidence of 95%.

Validity
Suitability of the investigative procedure to answer the question being asked. For example, an investigation to find out if the rate of a chemical reaction depended upon the concentration of one of the reactants would not be a valid procedure if the temperature of the reactants was not controlled.

Valid conclusion
A conclusion supported by valid data, obtained from an appropriate experimental design and based on sound reasoning.

Variables
These are physical, chemical or biological quantities or characteristics.

Categoric variables
Categoric variables have values that are labels. E.g. names of plants or types of material.

Continuous variables
Continuous variables can have values (called a quantity) that can be given a magnitude either by counting (as in the case of the number of shrimp) or by measurement (e.g. light intensity, flow rate etc.).

Control variables
A control variable is one which may, in addition to the independent variable, affect the outcome of the investigation and therefore must be kept constant or at least monitored.

Dependent variables
The dependent variable is the variable of which the value is measured for each change in the independent variable.

Independent variables
The independent variable is the variable for which values are changed or selected by the investigator.

IMPORTANT NOTE
These definitions must be memorised by students.

You will be tested on your knowledge of these definitions.

TOPIC: 3.4.1.1 Scalars and Vectors
SPEC CHECK

Specification	Completed?
Nature of scalars and vectors. Examples should include: velocity/speed, mass, force/weight, acceleration, displacement/distance.	
Addition of vectors by calculation or scale drawing. Calculations will be limited to two vectors at right angles. Scale drawings may involve vectors at angles other than 90°.	
Resolution of vectors into two components at right angles to each other. Examples should include components of forces along and perpendicular to an inclined plane. Problems may be solved either using resolved forces or the use of a closed triangle.	
Conditions for equilibrium for two or three coplanar forces acting at a point. Appreciation of the meaning of equilibrium in the context of an object at rest or moving with constant velocity.	
Investigation of the conditions for equilibrium for three coplanar forces acting at a point using a force board.	

NOTES

These notes are brief.

More detailed notes are found in the student preparatory reading book.

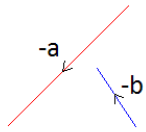
Please read the preparatory reading notes.

What is a Vector?
A vector is a physical quantity that has both magnitude (size) and direction.
Examples of Vectors: Displacement, velocity, force, acceleration and momentum.

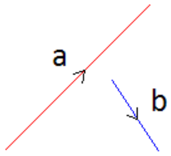
What is a Scalar?
A scalar is a physical quantity that has magnitude only (it doesn’t act in a certain direction).
Examples of Scalars: Distance, speed, energy, power, pressure, temperature and mass.

Vector Diagrams

A vector can be represented by a vector diagram as well as numerically:
The length of the line represents the magnitude of the vector.
The direction of the line represents the direction of the vector.
We can see that vector **a** has a greater magnitude than vector **b** but acts in a different direction.



A negative vector means a vector of equal magnitude but opposite direction.

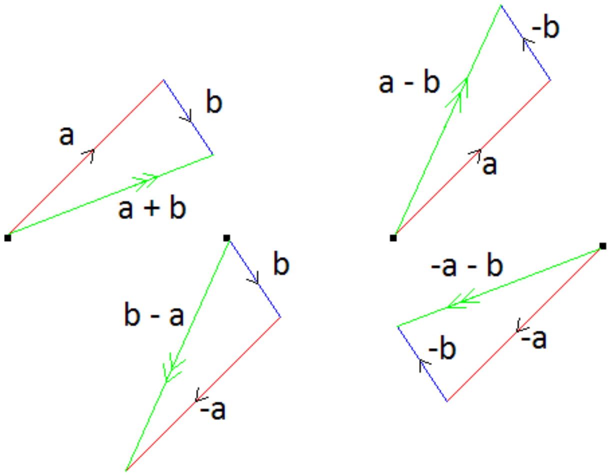


Adding Vectors

We can add vectors together to find the affect that two or more would have if acting at the same time. This is called the resultant vector.
We can find the resultant vector in four ways: Scale drawing, Pythagoras, the Sine and Cosine rules and Resolving vectors.

Scale Drawing

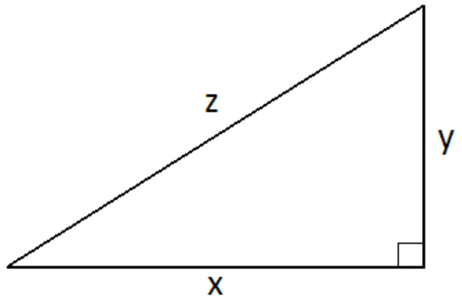
To find the resultant vector of **a** + **b** we draw vector **a** then draw vector **b** from the end of **a**. The resultant is the line that connects the start and finish points.
The resultants of **a** + **b, b** – **a, a** – **b,** – **a** – **b** and would look like this:



If the vectors were drawn to scale, we can find the resultant by measuring the length of the line and the angle.

Pythagoras

If two vectors are perpendicular to each other the resultant can be found using Pythagoras:



Vector **z** is the resultant of vectors **x** and **y**.

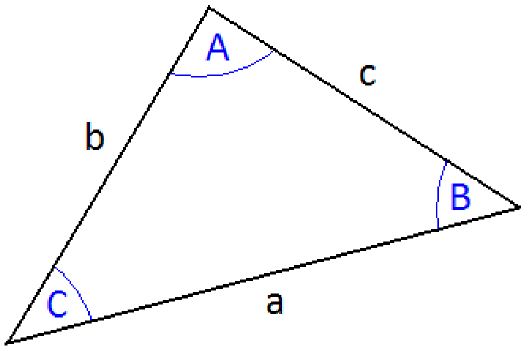
Since **x** and **y** are perpendicular $z^2 = x^2 + y^2 \rightarrow z = \sqrt{x^2 + y^2}$

We can also use this in reverse to find **x** or **y**:

$$z^2 = x^2 + y^2 \rightarrow z^2 - y^2 = x^2 \rightarrow \sqrt{z^2 - y^2} = x$$

$$z^2 = x^2 + y^2 \rightarrow z^2 - x^2 = y^2 \rightarrow \sqrt{z^2 - x^2} = y$$

Sine and Cosine Rules



The sine rule relates the angles and lengths using this equation:

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

The Cosine rule relates them using these equations:

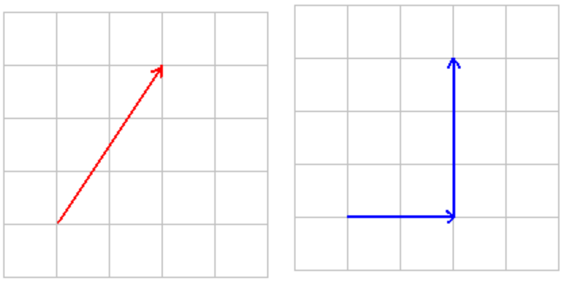
$$a^2 = b^2 + c^2 - 2bc\cos A$$

$$b^2 = a^2 + c^2 - 2ac\cos B$$

$$c^2 = a^2 + b^2 - 2ab\cos C$$

Resolving Vectors

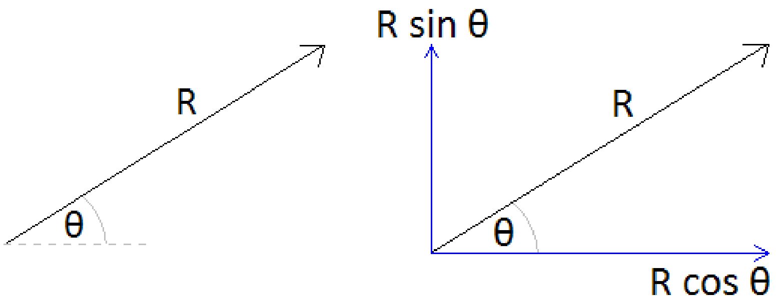
A vector can be 'broken down' or *resolved* into its vertical and horizontal components.



We can see that this vector can be resolved into two perpendicular components, in this case two to the right and three up.

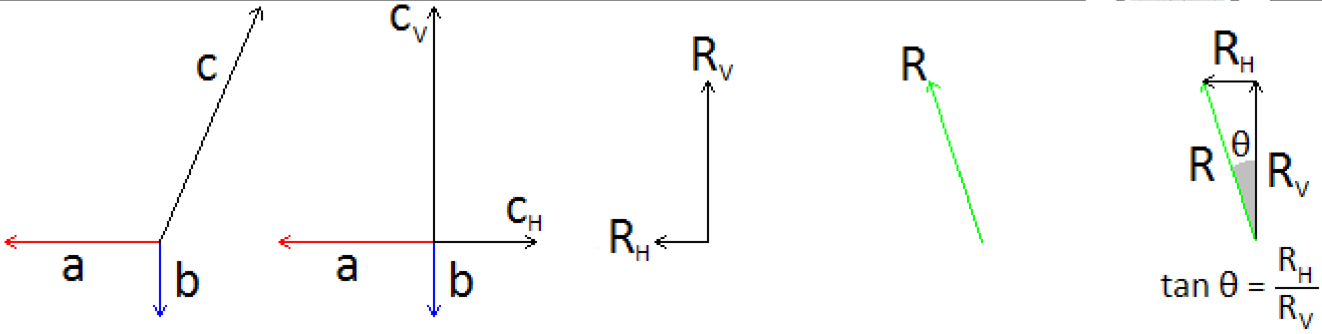
This is obvious when it is drawn on graph paper but becomes trickier when there isn't a grid and still requires an element of scale drawing.

We can calculate the vertical and horizontal components if we know the magnitude and direction of the vector. In other words; we can work out the across and upwards bits of the vector if we know the length of the line and the angle between it and the horizontal or vertical axis.



Adding Resolved Vectors

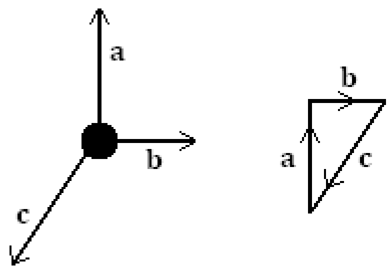
Now that we can resolve vectors into the vertical and horizontal components it is made from we can add them together. Look at this example of multiple vectors acting (**A**).



A **B** **C** **D** **E**

If we resolve the vector **c** we get (**B**). We can now find the resultant of the horizontal components and the resultant of the vertical components (**C**). We can then add these together to find the resultant vector (**D**) and the angle can be found using trigonometry (**E**)

Equilibrium



When all the forces acting on a body cancel out equilibrium is reached and the object does not move. As you sit and read this the downwards forces acting on you are equally balanced by the upwards forces, the resultant it that you do not move.

With scale drawing we can draw the vectors, one after the other. If we end up in the same position, we started at then equilibrium is achieved.
With resolving vectors, we can resolve all vectors into their vertical and horizontal components. If the components up and down are equal and the components left and right are equal equilibrium has been reached.

REVISION SHEET

Highlight or underline the key information on the revision sheet to consolidate your understanding.

Scalars** Only Have **Size**, but **Vectors** Have **Size** and **Direction

1) A **scalar** has **no direction** — it's **just an amount** of something, like the **mass** of a **sack of meaty dog food**.
2) A **vector** has magnitude (**size**) and **direction** — like the **speed and direction** of next door's **cat** running away.
3) **Force**, **velocity and momentum** are all **vectors** — you need to know **which way** they're going as well as **how big** they are. Here are some of the common scalars and vectors that you'll come across in your exams:

Scalars	Vectors
mass, time, energy temperature, length, speed	displacement, force, velocity, acceleration, momentum

4) Vectors are drawn as **arrows** (to show their direction) with their **size** written next to them (see Example 1 below). In the exam, you might see quantities written with **arrows** above them, e.g. $\vec{v}$, to show that they're vectors.

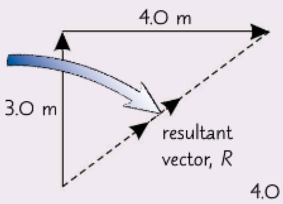
Sometimes vectors are printed in bold, e.g. ***v***, but it's quite hard to handwrite in bold, so the arrow is used too.

*You can **Add** Vectors to Find the **Resultant***

1) Adding two or more vectors is called finding the **resultant** of them.
2) You should always start by drawing a **diagram**. Draw the vectors '**tip to tail**'. If you're doing a **vector subtraction**, draw the vector you're subtracting with the same magnitude but pointing in the **opposite direction**.
3) If the vectors are at **right angles** to each other, then you can use **Pythagoras** and **trigonometry** to find the resultant.
4) If the vectors aren't at right angles, you may need to draw a **scale diagram**.

Example 1: Jemima goes for a walk. She walks 3.0 m north and 4.0 m east. She has walked 7.0 m but she isn't 7.0 m from her starting point. Find the magnitude and direction of her displacement.

First, draw the vectors **tip-to-tail**. Then draw a line from the **tail** of the first vector to the **tip** of the last vector to give the **resultant**:

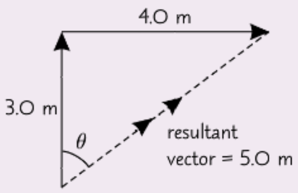


Jemima's 'displacement' gives her position relative to her starting point, see p.16.

Because the vectors are at right angles, you get the **magnitude** of the resultant using Pythagoras:

$R^2 = 3.0^2 + 4.0^2 = 25.0$ So $R = \mathbf{5.0\ m}$

Now find the **bearing** of Jemima's new position from her original position.



Jemima

You use the triangle again, but this time you need to use trigonometry. You know the opposite and the adjacent sides, so you can use:

$\tan\theta = 4.0 / 3.0$ So $\theta = \mathbf{053°}$ **(to 2 s.f.)**

Example 2: A van is accelerating north, with a resultant force of 510 N. A wind begins to blow on a bearing of 150°. It exerts a force of 200 N (to 2 s.f.) on the van. What is the new resultant force acting on the van?

A bearing is just an angle measured clockwise from the north line, represented by three digits, e.g. 10° = 010°

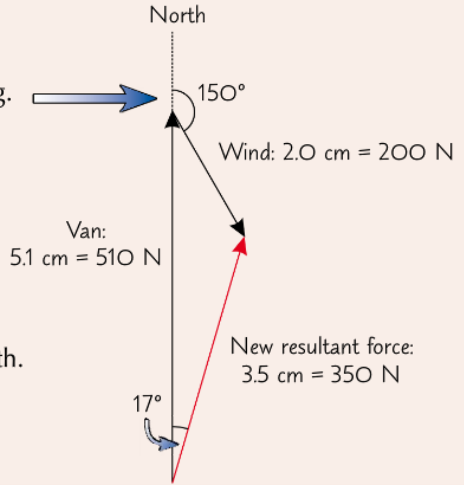
The vectors **aren't** at right angles, so you need to do a scale drawing. Pick a sensible scale. Here, 1 cm = 100 N seems good.

Using a really sharp pencil, draw the initial resultant force on the van. As the van is going north, this should be a 5.1 cm long line going straight up.

The force of the wind acts on a bearing of 150°, so add this to your diagram. Using the same scale, this vector has a length of 2.0 cm.

Then you can draw on the new resultant force and measure its length. Measure the angle carefully to get the bearing.

The resultant force has a magnitude of 350 N (to 2 s.f.), acting on a bearing of 017° (to 2 s.f.).



It's Useful to Split a ***Vector*** *into* ***Horizontal*** *and* ***Vertical Components***

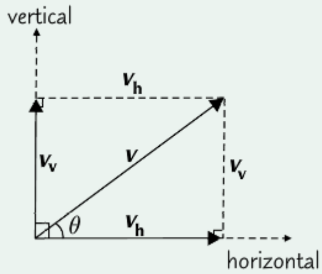
This is the opposite of finding the resultant — it's called **resolving**. You start from the resultant vector and split it into two **components** at right angles to each other. You're basically **working backwards** from Example 1 on the last page.

Resolving a vector *v* into horizontal and vertical components:

You get the **horizontal** component v_h like this:

$\cos\theta = v_h / v$

$$v_h = v\cos\theta$$



...and the **vertical** component v_v like this:

$\sin\theta = v_v / v$

$$v_v = v\sin\theta$$

Where θ is the angle from the horizontal.

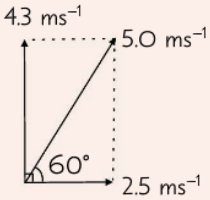
Example: Charley's amazing floating home is travelling at a speed of 5.0 ms^{-1} at an angle of 60° (to 2 s.f.) up from the horizontal. Find the vertical and horizontal components.

The **horizontal** component v_h is:

$v_h = v\cos\theta = 5.0\cos 60° = \mathbf{2.5\ ms^{-1}}$

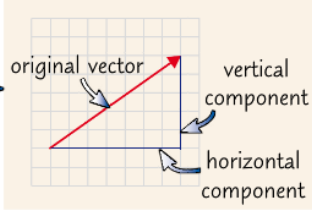
The **vertical** component v_v is:

$v_v = v\sin\theta = 5.0\sin 60° = \mathbf{4.3\ ms^{-1}}$ **(to 2 s.f.)**



Charley's mobile home was the envy of all his friends.

You can also resolve vectors using **scale drawings**. It's easiest to do this on **squared paper**. Just draw the vector to **scale** in the **correct direction**, then draw a **horizontal** line and **vertical** line from the tip and tail of the vector to form a **right-angled triangle**. Then measure the **lengths** of the lines and use the **scale** to convert them — this gives you the **horizontal** and **vertical** components of the vector.



Resolving is dead useful because the two components of a vector **don't affect each other**. This means you can deal with the two directions **completely separately** (there's more on this on page 20).

Reference: CGP Revision Guide

Additional Note Space

Additional Note Space

PUZZLES

To improve your understanding, answer the following puzzles.

The answers are overleaf.

QUESTIONS

1 Two forces act on a wooden block, one to the right of 3 N and the other to the left of 5 N. Draw a scale diagram of these vectors. What are the magnitude and direction of the resultant force on the block measured from the diagram?

2 A boat leaves harbour and travels due north for a distance of 3 km and then due west for a distance of 8 km. What is the final displacement of the boat with respect to the harbour? The boat then travels a further distance of 1 km due south. What is the new displacement with respect to the harbour?

3 A helicopter rises vertically from the ground for a distance of 600 m and then moves horizontally for a distance of 1.6 km. Draw a scale diagram to calculate the displacement of the helicopter from its starting point.

4 Repeat the above calculation using only mathematical equations.

5 A boat is pulled along a canal using a rope tied to its bow. The rope makes an angle of 15° with the centre line of the canal and the force applied to the rope is 1800 N. Using either mathematics or scale diagrams, calculate the force pulling the boat along the canal and the force pulling the boat to the side of the canal.

6 After take-off, an aircraft climbs at a rate of 150 m s^{-1} at an angle of 30° to the ground. What are the magnitudes of the horizontal and vertical components of its velocity?

Answering Space

ANSWERS

1 2 N to the left.

2 8.54 km, 69°W of N; 8.24 km, 76°W of N.

3 1.7 km, 20.5° above the horizontal.

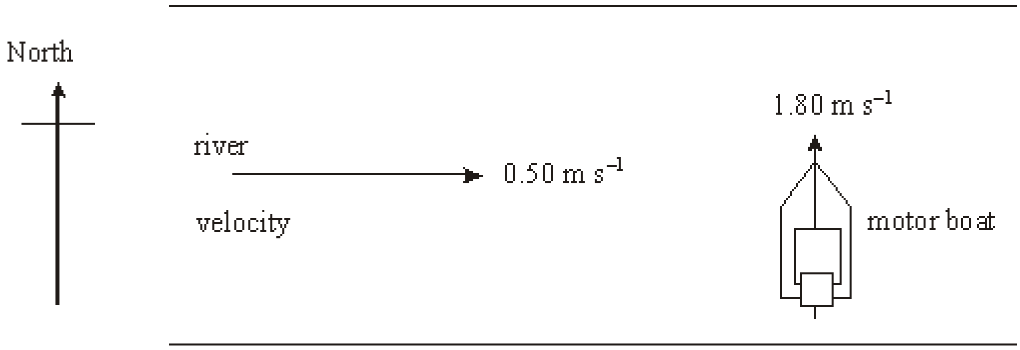
4 As above.

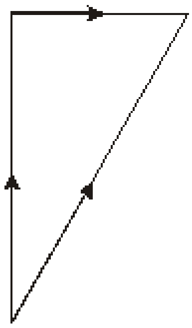
5 1739 N along the canal, 466 N to the side of the canal.

6 130 m s^{-1} horizontal velocity, 75 m s^{-1} vertical velocity.

SAMPLE QUESTION

Q1. The figure below shows a river which flows from West to East at a constant velocity of 0.50 m s^{-1}. A small motor boat leaves the south bank heading due North at 1.80 m s^{-1}.
Find, by scale drawing or otherwise, the resultant velocity of the boat.





or *use of* $c^2 = a^2 + b^2$ or *use of* $\tan\theta = a/b$

1 mark

$v^2 = 1.80^2 + 0.50^2$

1 mark

$\theta = \tan^{-1}(0.50/1.80)$ *or other valid angle*

1 mark

speed = 1.87 ms^{-1}

1 mark

direction N 15.5° E
or unambiguous alternative

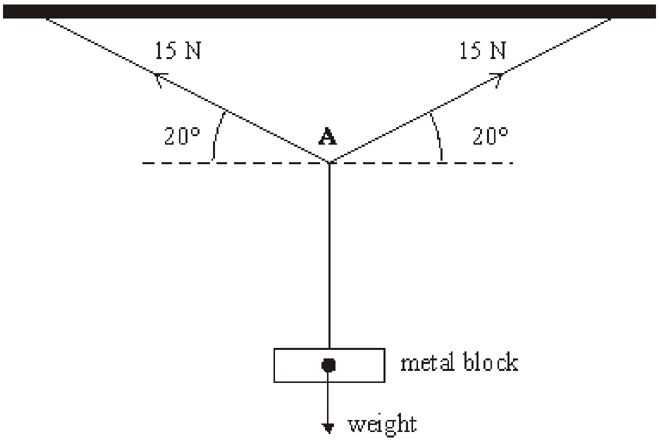
1 mark

(Total 5 marks)

Reference: AQA Legacy Examination Materials Specimen B

SELF ASSESSMENT

A1. The figure below shows a stationary metal block hanging from the middle of a stretched wire which is suspended from a horizontal beam. The tension in each half of the wire is 15 N.



Calculate for the wire at **A**,

A1.1 The resultant horizontal component of the tension forces,

[2 Marks]

....

....

A1.2 The resultant vertical component of the tension forces.

[1 Mark]

....

....

A1.3 State the weight of the metal block.

[1 Mark]

....

....

A1.4 Explain how you arrived at your answer, with reference to an appropriate law of motion.

[2 Marks]

....

....

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Reference: AQA Legacy Examination Materials Specimen A

A2.1 State what is meant by a scalar quantity.

[1 Mark]

....

....

....

....

A2.2 State **two** examples of scalar quantities.

[3 Marks]

Example 1:

....

....

Example 2:

....

....

An object is acted upon by two forces at right angles to each other. One of the forces has a magnitude of 5.0 N and the resultant force produced on the object is 9.5 N.
Determine

A2.3 The magnitude of the other force,

[3 Marks]

....

....

....

....

....

....

A2.4 The angle between the resultant force and the 5.0 N force.

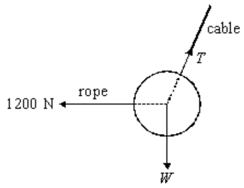
[1 Mark]

....

....

Reference: AQA Legacy Examination Materials Specimen A

Q3. The diagram shows a 250 kg iron ball being used on a demolition site. The ball is suspended from a cable at point **A** and is pulled into the position shown by a rope that is kept horizontal. The tension in the rope is 1200 N.



In the position shown the ball is in equilibrium.

A3.1 What balances the force of the rope on the ball?

[1 Mark]

....

....

A3.2 What balances the weight of the ball?

[1 Mark]

....

....

Determine

A3.3 The magnitude of the vertical component of the tension in the cable,

[1 Mark]

....

....

A3.4 The magnitude of the horizontal component of the tension in the cable,

[1 Mark]

....

....

A3.5 The magnitude of the tension in the cable,

[2 Marks]

....

....

....

A3.6 the angle the cable makes to the vertical.

[2 Marks]

....

....

Reference: AQA Legacy Examination Materials Specimen A

TOPIC: 3.4.1.2 Moments

SPEC CHECK

Specification	Completed?
Moment of a force about a point. Moment defined as *force × perpendicular distance from the point to the line of action of the force*.	
Couple as a pair of equal and opposite coplanar forces. Moment of couple defined as *force × perpendicular distance between the lines of action of the forces*.	
Principle of moments.	
Centre of mass. Knowledge that the position of the centre of mass of uniform regular solid is at its centre.	

These notes are brief.

More detailed notes are found in the student preparatory reading book.

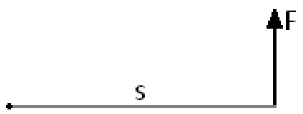
Please read the preparatory reading notes.

NOTES

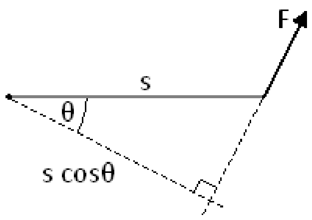
Moments

The moment of a force is its turning affect about a fixed point (pivot).
The magnitude of the moment is given by:
moment = force x perpendicular distance from force to the pivot

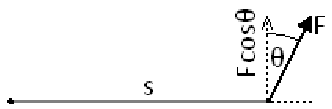
$$moment = Fs$$



In this diagram, we can see that the force is not acting perpendicularly to the pivot.
We must find the perpendicular or closest distance, this is $s\cos\theta$.
The moment in this case is given as: $moment = Fs\cos\theta$



We could have also used the value of s but multiplied it by the vertical component of the force.
This would give us the same equation.



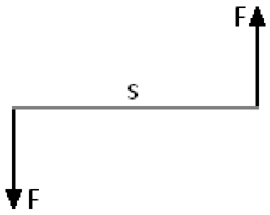
$$moment = F\cos\theta.s$$

Moments are measured in Newton metres, Nm

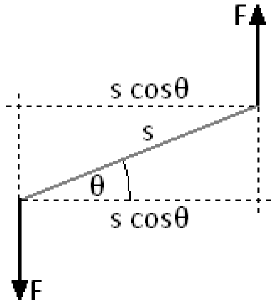
Couples

A couple is a pair of equal forces acting in opposite directions. If a couple acts on an object it rotates in position. The moment of a couple is called the torque.
The torque is calculated as: torque = force x perpendicular distance between forces

$$\boxed{torque = Fs}$$



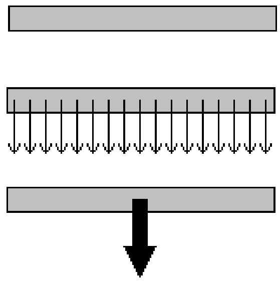
In the diagram to the right we need to calculate the perpendicular distance, $s\cos\theta$.
So in this case: $$\boxed{torque = Fs\cos\theta}$$



Torque is measured in Newton metres, Nm

Centre of Mass

If we look at the ruler to the right, every part of it has a mass. To make tackling questions easier we can assume that all the mass is concentrated in a single point.



Centre of Gravity

The centre of gravity of an object is the point where all the weight of the object appears to act. It is in the same position as the centre of mass.

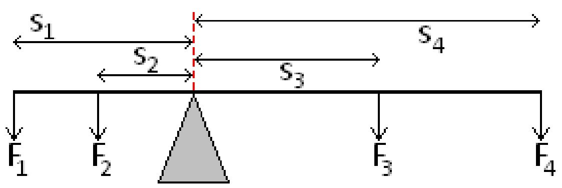
We can represent the weight of an object as a downward arrow acting from the centre of mass or gravity. This can also be called the line of action of the weight.

Balancing

When an object is balanced:

$$\boxed{\textit{the total moments acting clockwise = the total moments acting anticlockwise}}$$

An object suspended from a point (e.g. a pin) will come to rest with the centre of mass directly below the point of suspension.
If the seesaw to the left is balanced then the clockwise moments must be equal to the anticlockwise moments.



Clockwise moment due to 3 and 4

$$moment = F_3 s_3 + F_4 s_4$$

Anticlockwise moments due to 1 and 2

$$moment = F_1 s_1 + F_2 s_2$$

So $$F_3 s_3 + F_4 s_4 = F_1 s_1 + F_2 s_2$$

Stability

The stability of an object can be increased by lowering the centre of mass and by widening the base.

An object will topple over if the line of action of the weight falls outside of the base.

REVISION SHEET

Highlight or underline the key information on the revision sheet to consolidate your understanding.

A *Moment* is the *Turning Effect* of a *Force*

The **moment** of a **force** depends on the **size** of the force and **how far** the force is applied from the **turning point** (also called the **axis of rotation**):

The line of action of a force is a line along which it acts.

moment of a force (in Nm) = **force** (in N) × **perpendicular distance from the line of action of the force to the axis of rotation** (in m)

$$M = Fx$$

Moments Must be *Balanced* or the *Object* will *Turn*

The **principle of moments** states that for a body to be in **equilibrium**, the **sum of the clockwise moments** about any point **equals** the **sum of the anticlockwise moments** about the same point.

Remember $\sum$ means "the sum of".

Example:

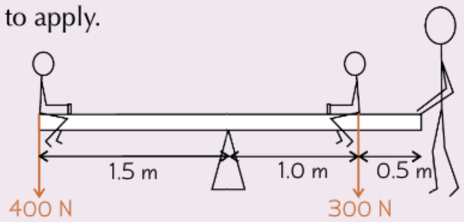
Two children sit on a seesaw as shown in the diagram. An adult balances the seesaw at one end. Find the size and direction of the force that the adult needs to apply.

In equilibrium, $\sum$ anticlockwise moments = $\sum$ clockwise moments

$$400 \times 1.5 = (300 \times 1.0) + 1.5F$$

$$600 = 300 + 1.5F$$

Final answer: F = **200 N downwards**



Muscles, *Bones* and *Joints* Act as *Levers*

1) In a lever, an **effort force** (in this case from a muscle) acts against a **load force** (e.g. the weight of your arm) by means of a **rigid object** (the bone) rotating around a **pivot** (the joint).
2) You can use the **principle of moments** to answer lever questions:

Example:

Find the force, E, exerted by the biceps in holding a bag of gold still. The bag of gold weighs 100 N and the forearm weighs 20 N.

Take moments about **A**.

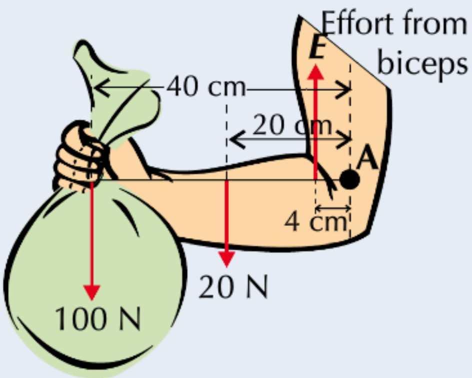
In equilibrium:

$\sum$ anticlockwise moments = $\sum$ clockwise moments

$$(100 \times 0.4) + (20 \times 0.2) = 0.04E$$

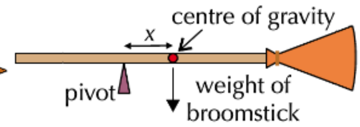
$$40 + 4 = 0.04E$$

Final answer: $E = 1100 =$ **1000 N (to 1 s.f.)**

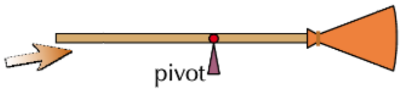


*The Principle of Moments can **Explain** why Things **Fall Over***

1) As you saw on page 39, you can assume that **all** the weight of an object **acts through** its **centre of gravity**. This is important when dealing with moments.
2) Imagine you are trying to balance a broomstick on a pivot. If the **centre of gravity** is to one side of the **pivot** (as shown here) then there will be a **clockwise** moment due to the **weight** of the broomstick acting at a **distance *x*** from the pivot. There is **no anticlockwise** moment, so the broomstick will **rotate** clockwise (fall off the pivot).



3) However, if the centre of gravity is **directly above** the pivot, then there are no clockwise or anticlockwise **moments** and so the broomstick is in **equilibrium**.



Example: Jamie Band is trying to save some top secret documents falling from a plank which is hanging precariously over a cliff. The diagram shows the plank pivoting at the edge of the cliff, labelled point P. He has tied a rope to one end of the plank and attached the other end of the rope to the ground. Jamie edges towards the top secret documents, but gets scared and stops at the point shown in the diagram below. Jamie has a mass of 75 kg and the top secret documents have a mass of 12 kg.

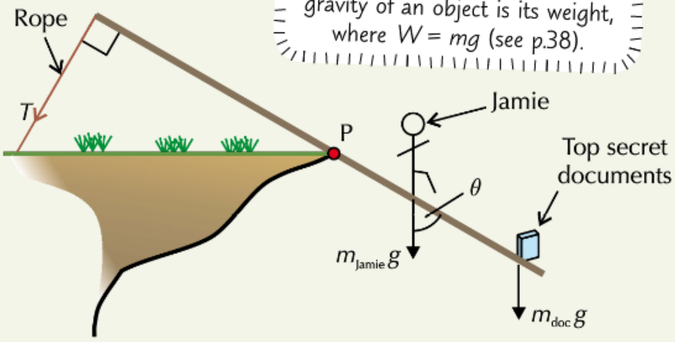
The distances and angles have been drawn to scale on the diagram below. Assuming the mass of the plank is negligible, calculate the tension, T, in the rope.

Remember — the force due to gravity of an object is its weight, where $W = mg$ (see p.38).

First you need to resolve all the forces (see p.26) acting perpendicular to the plank by measuring the angle between the line of action of Jamie's weight and the plank.

Angle $\theta = 60°$, so the force exerted by Jamie's weight acting perpendicular to the plank $= m_{Jamie}g \times \sin 60°$ and the force exerted by the documents acting perpendicular to the plank $= m_{doc}g \times \sin 60°$.

The angle between the rope and plank is 90°, so the tension acting perpendicular to the plank is just T.



You then need to measure all the distances: from P to rope = 3.6 cm, from P to Jamie = 1.2 cm, from P to documents = 2.8 cm. Using these values and the values for the forces, you can use the principle of moments to give:

Σ anticlockwise moments = Σ clockwise moments

$T \times 3.6 = (m_{Jamie}g \times \sin 60° \times 1.2) + (m_{doc}g \times \sin 60° \times 2.8)$

Which gives: $T = \dfrac{(75 \times 9.81 \times \sin 60° \times 1.2) + (12 \times 9.81 \times \sin 60° \times 2.8)}{3.6} = 291.68... =$ **290 N (to 2 s.f.)**

Reference: CGP Revision Guide

Additional Note Space

Additional Note Space

PUZZLES

To improve your understanding, answer the following puzzles.

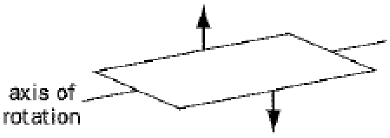
The answers are overleaf.

QUESTIONS

1 A force of 4 N is applied to the handle of a winch. If the arm is 30 cm long and the force is applied at right angles, what is the moment of the force?

2 A diver of mass 70 kg stands at the end of a diving board. The diving board has a length of 3.5 m to the point at which it is supported. Calculate the moment of the force about the point of support.

3 A small electric motor consists of a coil with dimensions 2 cm by 4 cm. When in a suitable magnetic field, current through the coil generate forces of magnitude 0.02 N at right angles to each of the sides. Calculate the couple provided.



4 A pendulum consists of a light string 0.8 m long to which is attached a mass of 300 g. At its maximum point of oscillation the string makes an angle of 6° to the vertical. Calculate the moment of the pendulum at this point about its point of suspension. At what point in the oscillation is the moment zero? How does the direction of the moment change during the oscillation?

5 Draw a sketch graph to show how the torque provided by a cyclist to the pedal wheel of a cycle varies with time. Assume that the force provided on the pedals is always vertically downwards.

Answering Space

ANSWERS

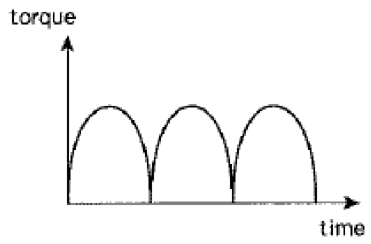
1 1.2 N m

2 2400 N m

3 4×10^{-4} N m

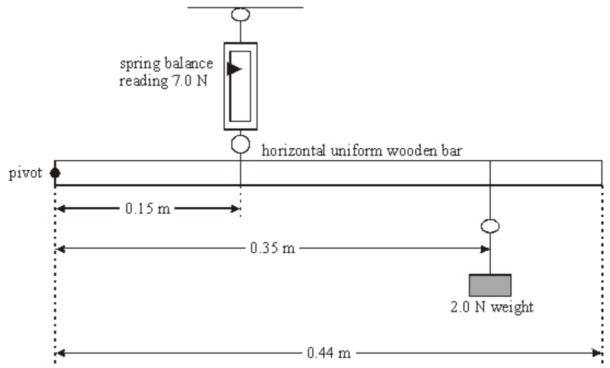
4 0.25 N m; at the centre of oscillation; positive and negative along the axis of rotation

5



SAMPLE QUESTION

Q1. A student set up the apparatus shown in the figure below to demonstrate the principle of moments.



Using the values on the figure calculate:

Q1.1 the magnitude of the moment about the pivot due to the tension of the spring in the spring balance;

1.05 (1.1) N m (or J)

1 mark

[1 Mark]

Q1.2 the magnitude of the moment about the pivot produced by the 2.0 N weight;

0.70 N m (condone 1 sf) **1 mark**

[1 Mark]

Q1.3 the weight of the wooden bar.

weight of bar = 1.59 N **1 mark**

[1 Mark]

Q1.4 Calculate the magnitude of the force exerted on the bar by the pivot.

3.4N

1 mark

[1 Mark]

Q1.5 State the direction of the force on the pivot.

[1 Mark]

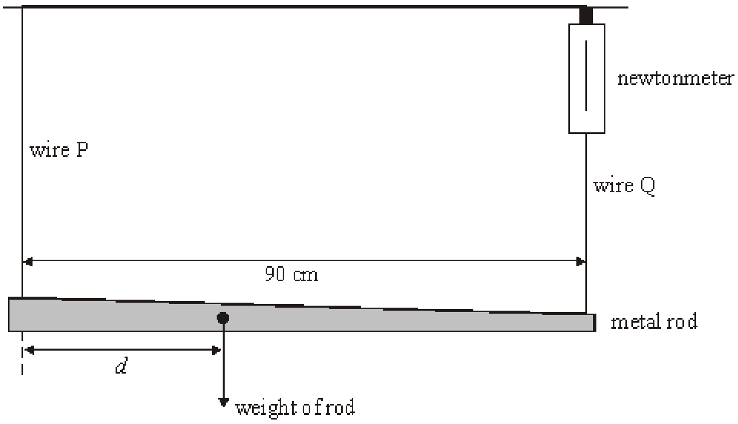
upwards (not clockwise)
(allow ecf for answer consistent with weight
i.e. down if (weight +2)>7)

1 mark

Reference: AQA Legacy Examination Materials Specimen B

SELF ASSESSMENT

A1. The figure below shows an apparatus used to locate the centre of gravity of a non-uniform metal rod.



The rod is supported horizontally by two wires, **P** and **Q** and is in equilibrium.

A1.1 State **two** conditions that must be satisfied for the rod to be in equilibrium.

[2 Marks]

....

....

....

....

Wire **Q** is attached to a newtonmeter so that the force the wire exerts on the rod can be measured. The reading on the newtonmeter is 2.0 N and the weight of the rod is 5.0 N.
Calculate

A1.2 The force that wire P exerts on the rod,

[1 Mark]

....

....

A1.3 The distance *d*.

[2 Marks]

....

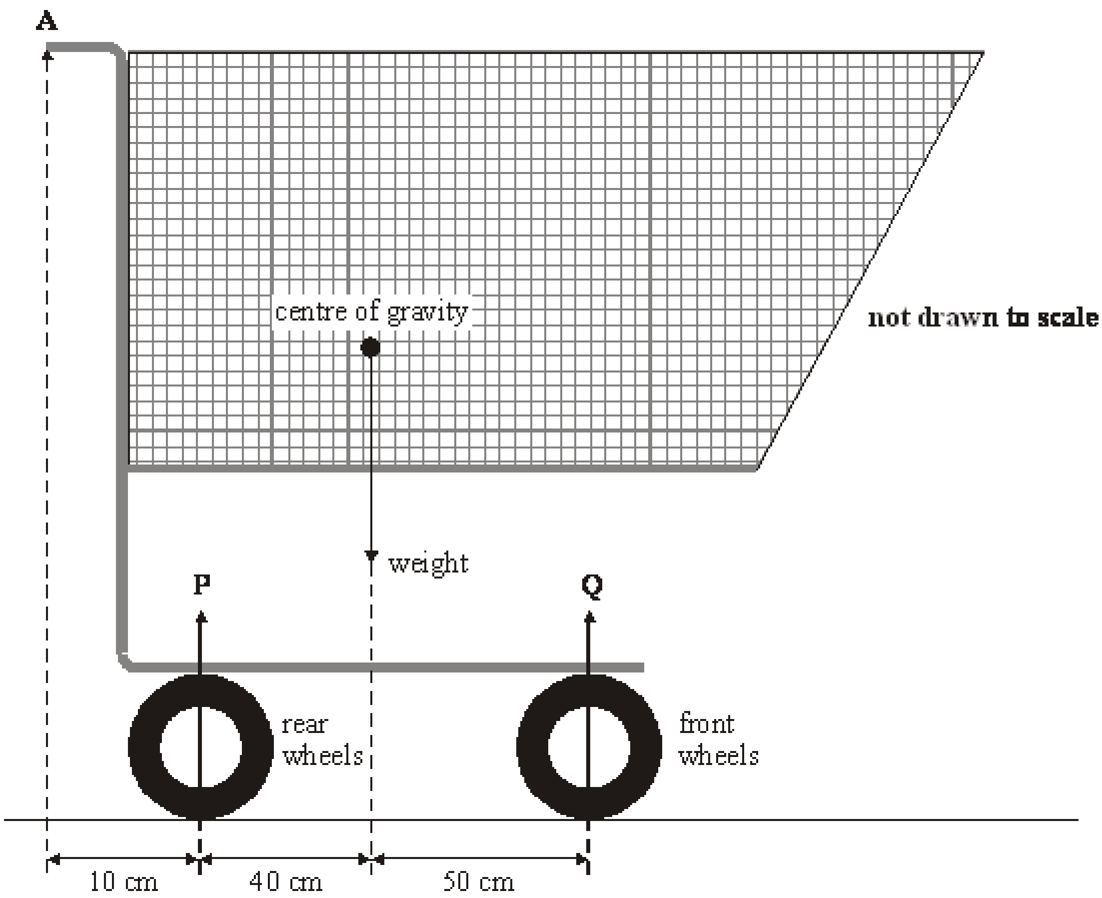
....

....

....

Reference: AQA Legacy Examination Materials Specimen A

A2. The figure below shows a supermarket trolley.



The weight of the trolley and its contents is 160 N.

A2.1 Explain what is meant by centre of gravity.

[2 Marks]

....

....

P and **Q** are the resultant forces that the ground exerts on the rear wheels and front wheels respectively. Calculate the magnitude of

A2.2 force **P**,

[2 Marks]

....

....

....

....

A2.3 force **Q**.

[1 Mark]

....

....

A2.4 Calculate the minimum force that needs to be applied vertically at **A** to lift the front wheels off the ground.

[2 Marks]

....

....

....

....

A2.5 State and explain, without calculation, how the minimum force that needs to be applied vertically at **A** to lift the rear wheels off the ground compares to the force you calculated in **part 2.4**

You may be awarded marks for the quality of written communication in your answer.

[3 Marks]

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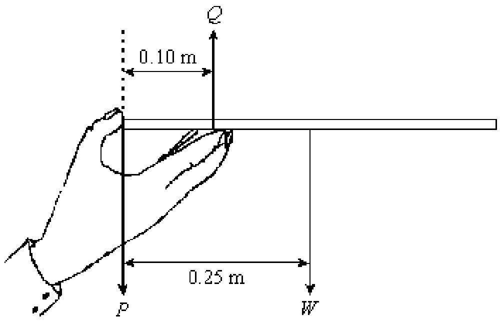
Reference: AQA Legacy Examination Materials Specimen A

A3. A waiter holds a tray horizontally in one hand between fingers and thumb as shown in the diagram.



P, *Q* and *W* are the three forces acting on the tray.

A3.1 State **two** relationships between the forces that must be satisfied if the tray is to remain horizontal and in equilibrium.

[2 Marks]

....

....

....

....

A3.2 If the mass of the tray is 0.12 kg, calculate the magnitude of the force *W*.

[2 Marks]

....

....

A3.3 Calculate the magnitudes of forces *P* and *Q*.

[2 Marks]

....

....

A3.4 The waiter places a glass on the tray. State and explain where the glass should be positioned on the tray if the force, *P*, is to have the same value as in part 3.1.

[2 Marks]

....

....

Reference: AQA Legacy Examination Materials Specimen A

TOPIC: 3.4.1.3 Motion Along A Straight Line

SPEC CHECK

Specification	Completed?
Displacement, speed, velocity, acceleration. $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$ Calculations may include average and instantaneous speeds and velocities.	
Representation by graphical methods of uniform and non-uniform acceleration.	
Significance of areas of velocity–time and acceleration–time graphs and gradients of displacement–time and velocity–time graphs for uniform and non-uniform acceleration e.g. graphs for motion of bouncing ball.	
Equations for uniform acceleration: $v = u + at$ $s = \frac{(u + v)}{2} t$ $s = ut + \frac{at^2}{2}$ $v^2 = u^2 + 2as$ Acceleration due to gravity, g.	
Distinguish between instantaneous velocity and average velocity.	
Measurements and calculations from displacement–time, velocity–time and acceleration–time graphs.	
Calculations involving motion in a straight line.	

NOTES

These notes are brief.

More detailed notes are found in the student preparatory reading book.

Please read the preparatory reading notes.

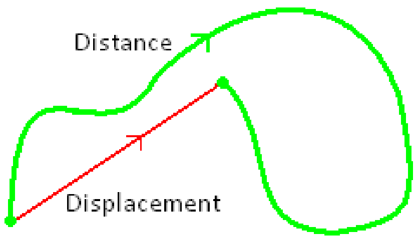
Distance

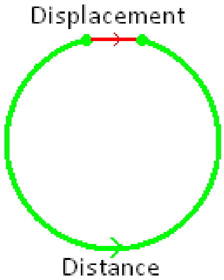
Distance is a scalar quantity. It is a measure of the total length you have moved.

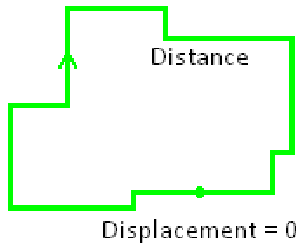
Displacement

Displacement is a vector quantity. It is a measure of how far you are from the starting position.

Distance and Displacement are measured in metres, m







Speed

Speed is a measure of how the distance changes with time. Since it is dependent on speed it too is a scalar.

$$speed = \frac{\Delta d}{\Delta t}$$

Velocity

Velocity is measure of how the displacement changes with time. Since it depends on displacement it is a vector too.

$$v = \frac{\Delta s}{\Delta t}$$

Speed and Velocity are is measured in metres per second, m/s
Time is measured in seconds, s

Acceleration

Acceleration is the rate at which the velocity changes. Since velocity is a vector quantity, so is acceleration. With all vectors, the direction is important. In questions, we decide which direction is positive (e.g. → +ve)

If a moving object has a positive velocity:
* a positive acceleration means an increase in the velocity
* a negative acceleration means a decrease in the velocity (it begins the 'speed up' in the other direction)

If a moving object has a negative velocity:
* a positive acceleration means an increase in the velocity (it begins the 'speed up' in the other direction)
* a negative acceleration means a increase in the velocity

If an object accelerates from a velocity of u to a velocity of v, and it takes t seconds to do it then we can write the equations as $a = \frac{(v-u)}{t}$ it may also look like this $a = \frac{\Delta v}{\Delta t}$ where Δ means the 'change in'

Acceleration is measured in metres per second squared, m/s²

Uniform Acceleration

In this situation, the acceleration is constant – the velocity changes by the same amount each unit of time.
For example: If acceleration is $2m/s^2$, this means the velocity increases by 2m/s every second.

Time (s)	0	1	2	3	4	5	6	7
Velocity (m/s)	0	2	4	6	8	10	12	14
Acceleration (m/s^2)		2	2	2	2	2	2	2

Non-Uniform Acceleration

In this situation, the acceleration is changing – the velocity changes by a different amount each unit of time.
For example:

Time (s)	0	1	2	3	4	5	6	7
Velocity (m/s)	0	2	6	10	18	28	30	44
Acceleration (m/s^2)		2	4	6	8	10	12	14

Before we look at the two types of graphs we use to represent motion, we must make sure we know how to calculate the gradient of a line and the area under it.

Gradient

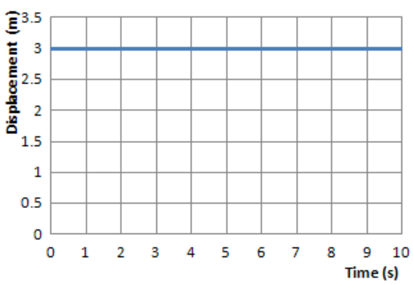
We calculate the gradient by choosing two points on the line and calculating the change in the y axis (up/down) and the change in the x axis (across).

$$gradient = \frac{\Delta y}{\Delta x}$$

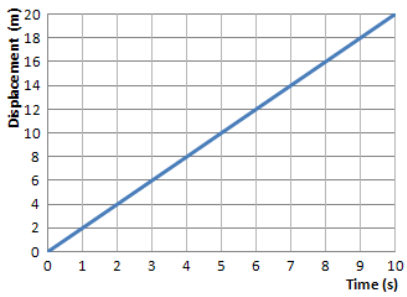
Area Under Graph

At this level, we will not be asked to calculate the area under curves, only straight lines.
We do this be breaking the area into rectangles (base x height) and triangles (½ base x height).

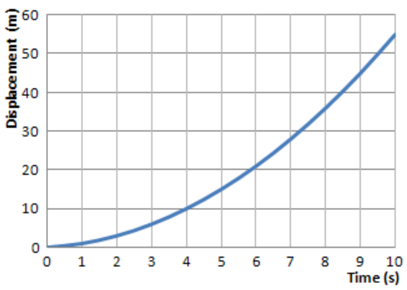
Displacement-Time Graphs



A



B



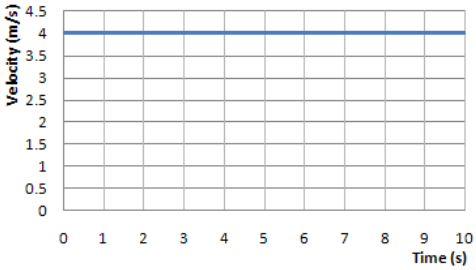
C

Graph A shows that the displacement stays at 3m, it is stationary.

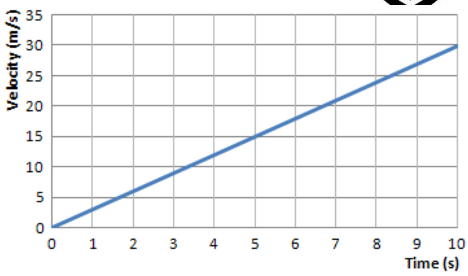
Graph B shows that the displacement increases by the same amount each second, it is travelling with constant velocity.
Graph C shows that the displacement covered each second increases each second, it is accelerating.

Since $gradient = \frac{\Delta y}{\Delta x}$ and y = displacement and x = time → $gradient = \frac{\Delta s}{\Delta t}$ → $\boxed{gradient = velocity}$

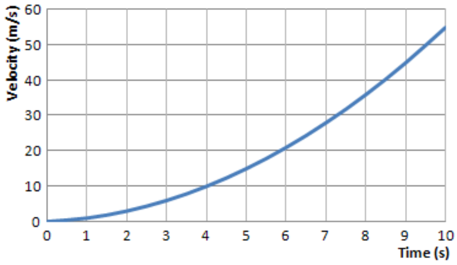
Velocity- Time Graphs



A



B



C

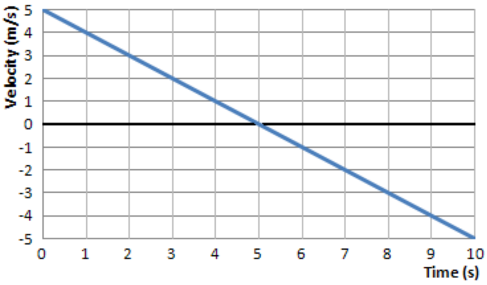
Graph A shows that the velocity stays at 4m/s, it is moving with constant velocity.

Graph B shows that the velocity increases by the same amount each second, it is accelerating by the same amount each second (uniform acceleration).

Graph C shows that the velocity increases by a larger amount each second, the acceleration is increasing (non-uniform acceleration).

Since $gradient = \frac{\Delta y}{\Delta x}$ and y = velocity and x = time → $gradient = \frac{\Delta v}{\Delta t}$ → $\boxed{gradient = acceleration}$

area = base x height → area = time x velocity → *area = displacement*



This graph show the velocity decreasing in one direction and increasing in the opposite direction.

If we decide that ←is negative and →is positive then the graph tells us:

The object is initially travels at 5 m/s → It slows down by 1m/s every second.

After 5 seconds the object has stopped
It then begins to move ← It gains 1m/s every second until it is travelling at 5m/s ←

Defining Symbols

Before we look at the equations we need to assign letters to represent each variable

Displacement	= ***s***	m	metres
Initial Velocity	= ***u***	m/s	metres per second
Final Velocity	= ***v***	m/s	metres per second
Acceleration	= ***a***	m/s^2	metres per second per second
Time	= ***t***	s	seconds

Equations of Motion

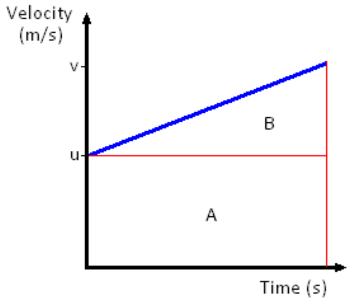
Equation 1

If we start with the equation for acceleration $a = \frac{(v-u)}{t}$ we can rearrange this to give us an equation 1

$at = (v-u)$ → $at + u = v$ $\boxed{v = u + at}$

Equation 2

We start with the definition of velocity and rearrange for displacement
velocity = displacement / time → displacement = velocity x time



In situations like the graph to the right the velocity is constantly changing, we need to use the average velocity.
displacement = average velocity x time

The average velocity is given by: average velocity = $\frac{(u+v)}{2}$

We now substitute this into the equation above for displacement

displacement = $\frac{(u+v)}{2}$ x time → $s = \frac{(u+v)}{2}t$ $\boxed{s = \tfrac{1}{2}(u+v)t}$

Equation 3

With Equations 1 and 2 we can derive an equation which eliminated *v*. To do this we simply substitute $v = u + at$ into $s = \tfrac{1}{2}(u+v)t$

$s = \tfrac{1}{2}(u + (u + at))t$ → $s = \tfrac{1}{2}(2u + at)t$ → $s = \tfrac{1}{2}(2ut + at^2)$ $\boxed{s = ut + \tfrac{1}{2}at^2}$

This can also be found if we remember that the area under a velocity-time graph represents the distance travelled/displacement. The area under the line equals the area of rectangle A + the area of triangle B.

Area = Displacement = $s = ut + \tfrac{1}{2}(v-u)t$ since $a = \frac{(v-u)}{t}$ then $at = (v-u)$ so the equation becomes

$s = ut + \tfrac{1}{2}(at)t$ which then becomes equation 3

Equation 4

If we rearrange equation 1 into $t = \frac{(v-u)}{a}$ which we will then substitute into equation 2:

$s = \tfrac{1}{2}(u+v)t$ → $s = \tfrac{1}{2}(u+v)\frac{(v-u)}{a}$ → $as = \tfrac{1}{2}(u+v)(v-u)$ → $2as = (v^2 + uv - uv - u^2)$ → $2as = v^2 - u^2$

$\boxed{v^2 = u^2 + 2as}$

Any question can be solved if three of the variables are given in the question.
Write down all the variables you have and the one you are asked to find, then see which equation you can use.
These equations can only be used for motion with UNIFORM ACCELERATION.

REVISION SHEET

Highlight or underline the key information on the revision sheet to consolidate your understanding.

Learn the **Definitions** of **Speed**, **Displacement**, **Velocity** and **Acceleration**

Displacement, velocity and acceleration are all **vector** quantities (page 14), so the **direction** matters.

Speed — How fast something is moving, regardless of direction.
Displacement (s) — How far an object's travelled from its starting point in a given direction.
Velocity (v) — The rate of change of an object's displacement (its speed in a given direction).
Acceleration (a) — The rate of change of an object's velocity.

During a journey, the **average speed** is just the **total distance** covered over the **total time** elapsed. The speed of an object at any given point in time is known as its **instantaneous** speed.

Uniform Acceleration is **Constant** Acceleration

Acceleration could mean a change in speed or direction or both.

Uniform means constant here. It's nothing to do with what you wear.

There are **four main equations** that you use to solve problems involving **uniform acceleration**. You need to be able to **use them**, but you don't have to know how they're **derived** — we've just put it in to help you learn them.

1) **Acceleration is the rate of change of velocity.**
From this definition you get:

$a = \frac{(v - u)}{t}$ so $\boxed{v = u + at}$

where:
u = initial velocity
v = final velocity
a = acceleration
t = time taken

2) **s = average velocity × time**
If acceleration is constant, the average velocity is just the average of the initial and final velocities, so:

$\boxed{s = \frac{(u + v)t}{2}}$ s = displacement

3) Substitute the expression for v from equation 1 into equation 2 to give:

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

$\boxed{s = ut + \tfrac{1}{2}at^2}$

4) You can **derive** the fourth equation from equations **1** and **2**:

Use equation **1** in the form: $a = \frac{v - u}{t}$ Multiply both sides by s, where: $s = \frac{(u + v)}{2} \times t$

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

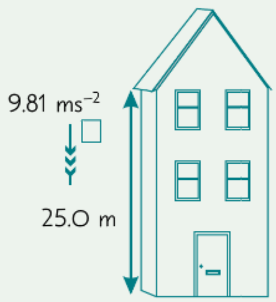
The t's on the right cancel, so:
$2as = (v - u)(v + u)$
$2as = v^2 - uv + uv - u^2$

so: $\boxed{v^2 = u^2 + 2as}$

Example: A tile falls from a roof 25.0 m high. Calculate its speed when it hits the ground and how long it takes to fall. Take $g = 9.81$ ms^{-2}.

First of all, write out what you know:
s = 25.0 m
u = 0 ms^{-1} since the tile's stationary to start with
a = 9.81 ms^{-2} due to gravity
v = ? t = ?

Usually you take upwards as the positive direction. In this question it's probably easier to take downwards as positive, so you get $g = +9.81$ ms^{-2} instead of $g = -9.81$ ms^{-2}.



Then, choose an equation with only **one unknown quantity**.
So start with $v^2 = u^2 + 2as$
$v^2 = 0 + 2 \times 9.81 \times 25.0$
$v^2 = 490.5$ v = **22.1 ms^{-1} (to 3 s.f.)**

Now, find t using:
$s = ut + \tfrac{1}{2}at^2$
$25.0 = 0 + \tfrac{1}{2} \times 9.81 \times t^2$
$t^2 = \frac{25.0}{4.905}$

Final answers:
t = **2.26 s (to 3 s.f.)**
v = **22.1 ms^{-1} (to 3 s.f.)**

Acceleration *Means a* ***Curved Displacement-Time Graph***

A graph of displacement against time for an **accelerating object** always produces a **curve**.
If the object is accelerating at a **uniform rate**, then the **rate of change** of the **gradient** will be constant.

Example: Plot a displacement-time graph for a lion who accelerates constantly from rest at 2 ms^{-2} for 5 seconds.

You want to find *s*, and you know that:
$a = 2\ ms^{-2}$
$u = 0\ ms^{-1}$

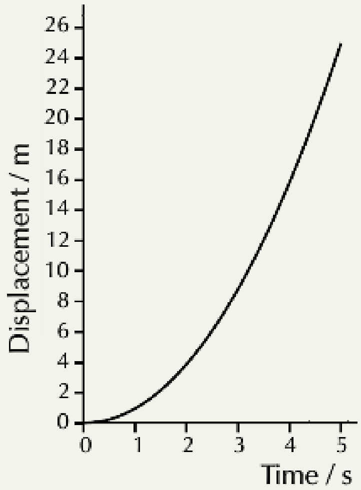
Use $s = ut + \frac{1}{2}at^2$

If you substitute in *u* and *a*, this simplifies to:
$s = 0 \times t + \frac{1}{2} \times 2t^2$
$s = t^2$

Do a **table of values**:

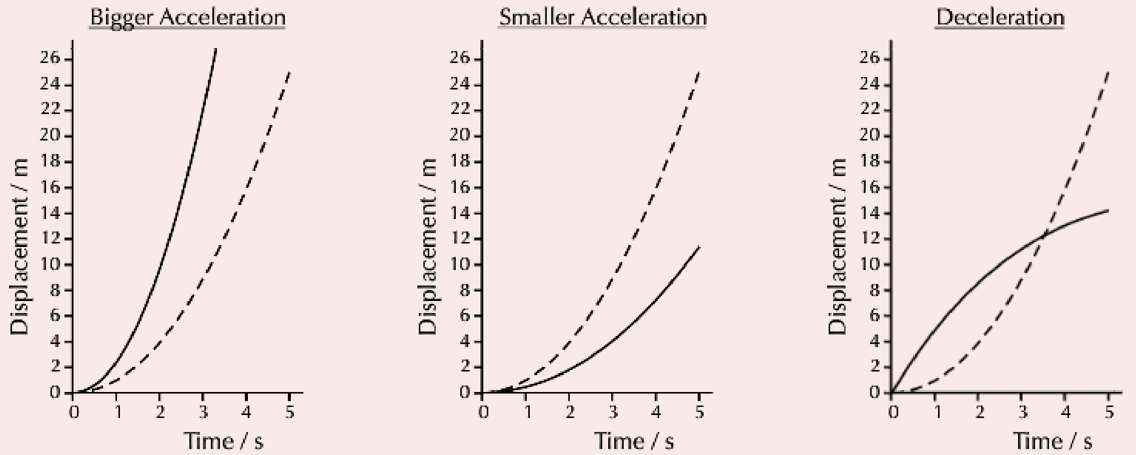
t / s	*s* / m
0	**0**
1	**1**
2	**4**
3	**9**
4	**16**
5	**25**

...then plot the **graph**:



Different Accelerations Have ***Different Gradients***

In the example above, if the lion has a **different acceleration** it'll change the **gradient** of the curve like this:



deceleration — the line has a decreasing gradient and curves the other way.

Norman (the lion).
Ooo, he's mean...

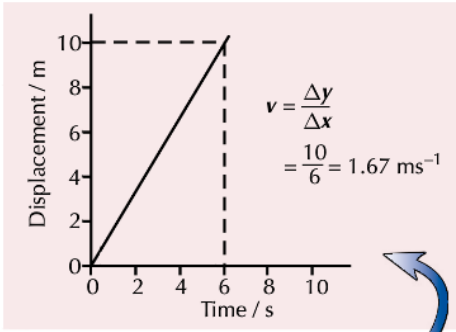
The **Gradient** of a **Displacement-Time Graph** Tells You the Velocity

When the velocity is constant, the graph's a **straight line**.
Velocity is defined as...

$$\textbf{velocity} = \frac{\textbf{change in displacement}}{\textbf{change in time}}$$

On the graph, this is $\frac{\text{change in } y\ (\Delta y)}{\text{change in } x\ (\Delta x)}$, i.e. the gradient.

So to get the velocity from a displacement-time graph, just find the gradient.



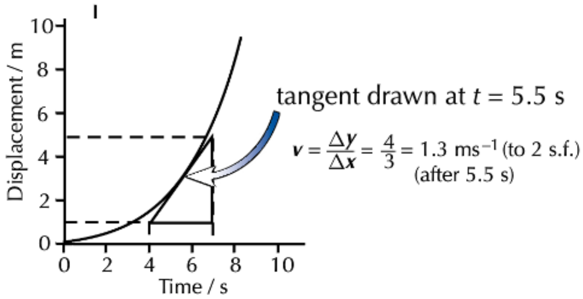
Acceleration is $\frac{\text{change in velocity } (\Delta v)}{\text{change in time } (\Delta t)}$, so it is the rate of change of this gradient. If the gradient is constant (straight line) then there is no acceleration, and if it's changing (curved line) then there's acceleration or deceleration.

It's the Same with **Curved Graphs**

If the gradient **isn't constant** (i.e. if it's a curved line), it means the object is **accelerating**.

To find the **instantaneous velocity** at a certain point you need to draw a **tangent** to the curve at that point and find its gradient.

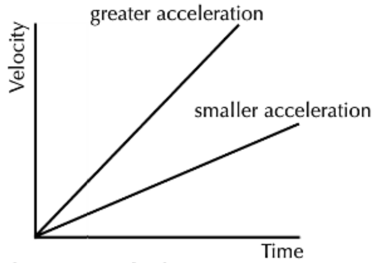
To find the **average velocity** over a period of time, just divide the final (change in) displacement by the final (change in) time — it doesn't matter if the graph is curved or not.



The **Gradient** of a **Velocity-Time Graph** tells you the **Acceleration**

$$\textbf{acceleration} = \frac{\textbf{change in velocity}}{\textbf{time taken}}$$

likewise for a speed-time graph



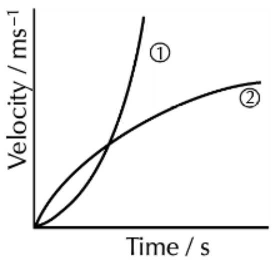
So the acceleration is just the **gradient** of a **velocity-time graph**.

1) **Uniform** acceleration is always a **straight line**.
2) The **steeper** the **gradient**, the **greater** the **acceleration**.

When the **acceleration** is **constant**, you get a **straight-line** v-t graph. The equation for a straight line is $y = mx + c$. You can rearrange the acceleration equation into the same form, getting $v = u + at$.
So on a linear v-t graph, **acceleration**, a, is the **gradient** (m) and the **initial speed**, u, is the **y-intercept** (c).

Acceleration isn't Always **Uniform**

1) If the acceleration is changing, the gradient of the velocity-time graph will also be changing — so you **won't** get a **straight line**.
2) **Increasing acceleration** is shown by an **increasing gradient** — like in curve ①.
3) **Decreasing acceleration** is shown by a **decreasing gradient** — like in curve ②.



Displacement = Area under Velocity-Time Graph

Similarly, the area under a speed-time graph is the total distance travelled.

You know that: **displacement = velocity × time**

The **area** under a velocity-time graph tells you the **displacement** of an object. Areas under any **negative** parts of the graph count as negative areas, as they show the object moving **back** to its **start point**.

Example: A racing car on a straight track accelerates uniformly from rest to 40 ms^{-1} in 10 s. It maintains this speed for a further 20 s before coming to rest by decelerating at a constant rate over the next 15 s. Draw a velocity-time graph for this journey and use it to calculate the total displacement of the racing car.

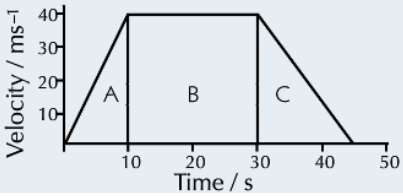
Split the **graph** up into **sections**: A, B and C. Calculate the **area** of each and **add** the three results together.

A: Area = ½ base × height = ½ × 10 × 40 = 200 m

B: Area = $b \times h$ = 20 × 40 = 800 m

C: Area = ½ $b \times h$ = ½ × 15 × 40 = 300 m

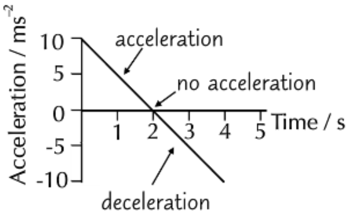
Total displacement = 1300 m



Acceleration-Time (a-t) Graphs are Useful Too

An **acceleration-time graph** shows how an object's **acceleration** changes over time.

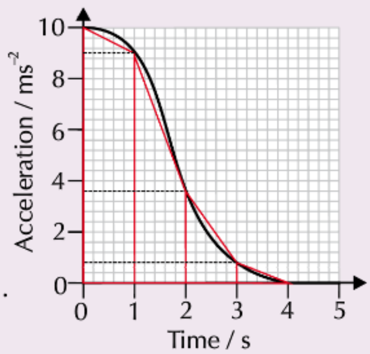
1) The **height** of the graph gives the object's **acceleration** at that time.
2) The **area** under the graph gives the object's **change in velocity**.
3) A negative acceleration is a **deceleration**.
4) If **$a = 0$**, then the object is moving with **constant velocity**.



You Have to *Estimate* the Area Under a *Curved* Graph

If an object's acceleration **isn't constant**, you won't get a straight line *a-t* graph. You need to know how to **estimate** the area under a curved graph. If the graph is on **squared paper**, you can work out the value represented by the **area** of **one** square and multiply by the approximate **number of squares** under the curve. Another way is to split the area approximately into simple shapes, calculate the value of the **area** of each of them, and then **add** them all up.

Example: The acceleration of a car in a drag race is shown in this acceleration-time graph. Calculate its change in velocity.



Change in velocity = area under graph

Split the area under the curve up into trapeziums and a triangle.

0-1 s — estimate the area using a trapezium. Area = $\frac{1}{2}(a + b) \times h$

a is the length of the first side, $a = 10$

b is the length of the second side, $b = 9$

h is the width of each strip, so $h = 1$. Area = $\frac{1}{2}(10 + 9) \times 1 = 9.5\ ms^{-1}$

1-2 s — this can also be estimated with another trapezium. $a = 9$, $b = 3.6$, $h = 1$.

So area = $\frac{1}{2}(9 + 3.6) \times 1 = 6.3\ ms^{-1}$

2-3 s — estimated with another trapezium. $a = 3.6$, $b = 0.8$, $h = 1$. So area = $\frac{1}{2}(3.6 + 0.8) \times 1 = 2.2\ ms^{-1}$

3-4 s — this estimation uses a triangle. Area = $\frac{1}{2}(\text{base} \times \text{height}) = \frac{1}{2}(0.8) \times 1 = 0.4\ ms^{-1}$

Now add the areas together — Total area = 9.5 + 6.3 + 2.2 + 0.4 = 18.4 ms^{-1}

The estimated change in velocity of the car is 18.4 ms^{-1} = **20 ms^{-1} (to 1 s.f.)**

You can use the same method to find the area under any non-linear graph.

Reference: CGP Revision Guide

Additional Note Space

Additional Note Space

PUZZLES

To improve your understanding, answer the following puzzles.

The answers are overleaf.

QUESTIONS

1 The performance data of a car states that from a standing start the car will reach a speed of 30 m s^{-1} in 12 s. Calculate the acceleration of the car and the distance it travels in that time?

2 Two cars are travelling towards each other on a single-track road with equal speeds of 35 m s^{-1}. When they are a distance of 500 m apart, they both decide to brake.

(a) What minimum equal decelerations would they require just to avoid an accident?

The brakes on one car fail and it continues with the same speed. The other car slows down and at the point of collision it has just stopped.

(b) What distances have the two cars travelled when the collision occurs?

(c) What time has elapsed?

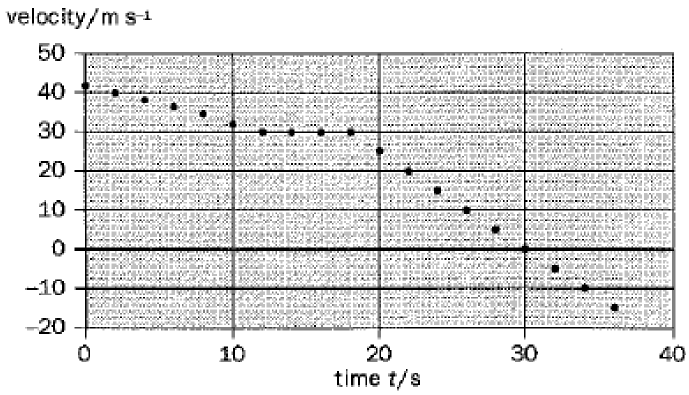
3 A police car stationary on the side of the road sees a car passing at a speed of 40 m s^{-1}. The police car immediately gives chase and accelerates at 3.0 m s^{-2} for 16 s, followed by a constant speed.

(a) How long does it take for the police car to catch up the speeding motorist?

(b) What distance will the police car have travelled?

4 The nuclei of helium atoms, alpha particles, leave atomic nuclei with a velocity of 3.5×10^7 m s^{-1}. They travel a distance of 7 cm prior to stopping. What uniform deceleration do they have and how long does it take them to stop?

5 The velocity of a car is monitored over a short period of time and has the following velocity–time graph.



(a) Describe the motion of the car.

(b) What is the acceleration of the car at $t = 6$ s, $t = 16$ s and $t = 30$ s?

(c) How far has the car travelled during the time from 0 to 30 s?

Answering Space

ANSWERS

1 2.5 m s^{-1}; 180 m

2 (a) 2.45 m s^{-2}
(b) 333 m 167 m
(c) 9.5 s

3 (a) 48 s
(b) 1920 m

4 8.75×10^{15} m s^{-2}; 4.0×10^{-9} s

5 (a) Deceleration 0–12 s; constant velocity 12–18 s; deceleration 18–30 s; instant stop at 30 s, acceleration reverse direction 30–36 s.
(b) –1.0 m s^{-2} 0 –2.5 m s^{-2}
(c) 792 m

SAMPLE QUESTION

S1. Figure 1 shows a graph of velocity against time for an aircraft of mass 2.8×10^4 kg landing on a stationary aircraft-carrier.

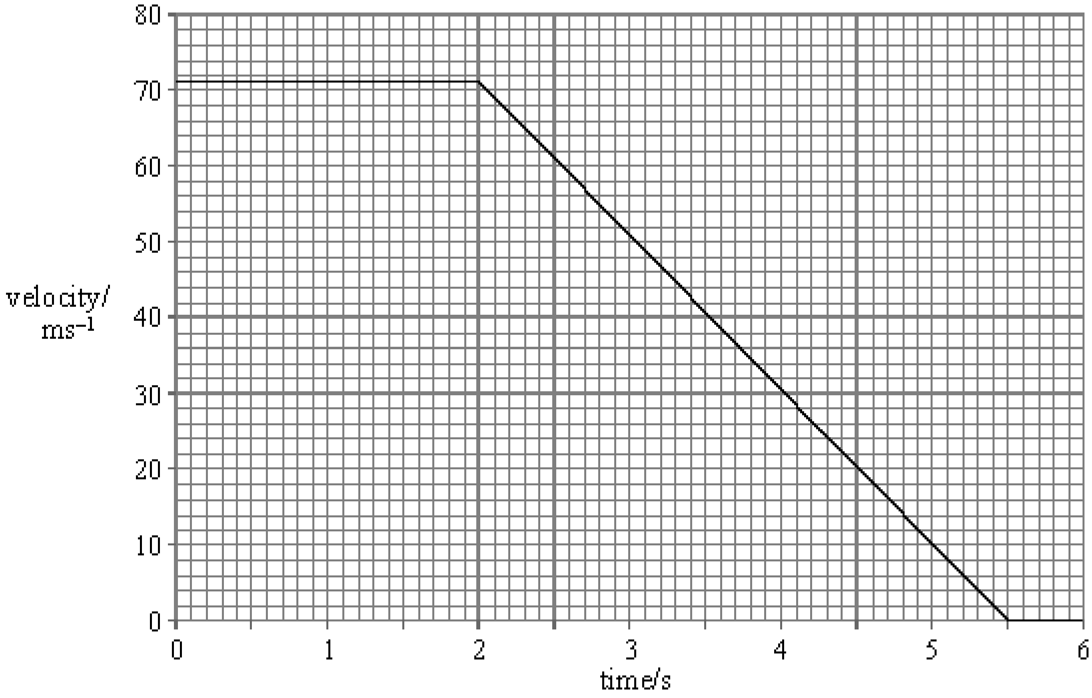


Figure 1

S1.1 Calculate the initial kinetic energy of the aircraft.

[2 Marks]

$\frac{1}{2} mv^2 = \frac{1}{2} \times 2.8 \times 10^4 \times 71^2$

1 mark

$= 7.1 \times 10^7$ J

1 mark

S1.2 Show that the deceleration of the aircraft is about 20 m s^{-2}.

[3 Marks]

deceleration = gradient of graph or $a = (v-u)/t$ or $\Delta v/\Delta t$ or evidence on graph

1 mark

= (71-0)/(3.5 – 0)

1 mark

= 20.3 [m s^{-2}]

1 mark

S1.3 Calculate the decelerating force acting on the aircraft.

[2 Marks]

[F=ma] = $2.8 \times 10^4 \times 20.3$

1 mark

=568 kN

1 mark

S1.4 A steam catapult is used to enable aircraft to take off from the ship. The catapult accelerates the aircraft from rest to its take-off speed of 71 m s^{-1} in a distance of 62 m.

Calculate the acceleration of the aircraft.

[2 Marks]

$v^2 = u^2 + 2as$
$a = v^2/2s = 71^2/124$
= 41 m s^{-2} [40.6]

2 marks

S1.5 In level flight, the pilot sets the course to be 80 m s^{-1} due north. There is a wind blowing from east to west at 20 m s^{-1}. Find, by scale drawing or otherwise, the resultant velocity of the aircraft.

[3 Marks]

drawing correct, scale clearly stated, wind speed line>+ 2 cm or one

1 mark

correct calculation
speed 82/83/82.5 m s^{-1} [80 – 84 if drawn]

1 mark

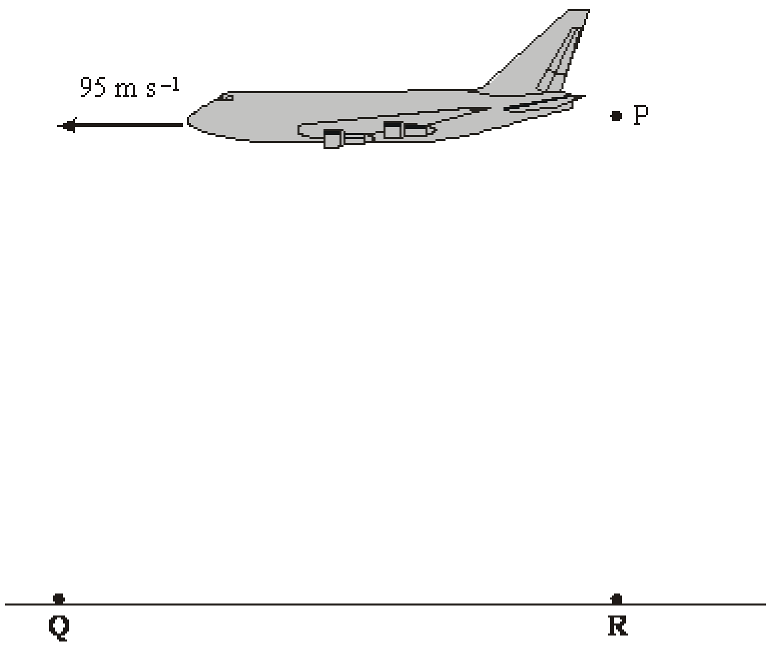
course 14° [12 – 16] west of north [346°]

1 mark

Reference: AQA Legacy Examination Materials Specimen B

SELF-ASSESSMENT

A1. The airplane shown in the diagram below is travelling horizontally at 95 m s^{-1}.
It has to drop a crate of emergency supplies.
The air resistance acting on the crate may be neglected.



A1. The crate is released from the aircraft at point **P** and lands at point **Q**. Sketch the path followed by the crate between **P** and **Q** as seen from the ground.

A1.1 Explain why the horizontal component of the crate's velocity remains constant while it is moving through the air.

[3 Marks]

....

....

A1.2 To avoid damage to the crate, the maximum vertical component of the crate's velocity on landing should be 32 m s^{-1}. Show that the maximum height from which the crate can be dropped is approximately 52 m.

[2 Marks]

....

....

A1.3 Calculate the time taken for the crate to reach the ground if the crate is dropped from a height of 52 m.

[2 Marks]

....

....

A1.4 If **R** is a point on the ground directly below **P**, calculate the horizontal distance **QR**.

[2 Marks]

....

....

A1.5 In practice air resistance is **not** negligible. State and explain the effect this has on the maximum height from which the crate can be dropped.

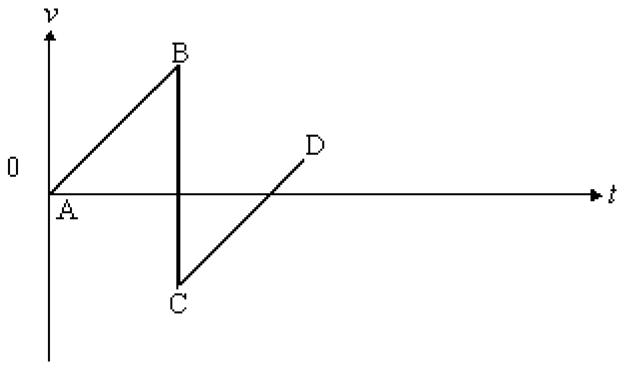
[2 Marks]

....

....

Reference: AQA Legacy Examination Materials Specimen A

A2. The diagram shows the velocity-time graph for a vertically bouncing ball, which is released above the ground at **A** and strikes the floor at **B**. The effects of air resistance have been neglected.



A2.1 What does the gradient of a velocity-time graph represent?

[1 Mark]

....

....

A2.2 Explain why the gradient of the line **CD** is the same as line **AB**.

[1 Mark]

....

....

A2.3 What does the area between the line **AB** and the time axis represent?

[1 Mark]

....

....

A2.4 State why the velocity at C is negative.

[1 Mark]

………

………

A2.5 State why the speed at C is less than the speed at B.

[2 Marks]

………

………

………

The ball has a mass of 0.15 kg and is dropped from an initial height of 1.2 m. After impact the ball rebounds to a height of 0.75 m.

Calculate

A2.6 The speed of the ball immediately before impact,

[2 Marks]

………

………

A2.7 The speed of the ball immediately after impact,

[2 Marks]

………

………

A2.8 The change in momentum of the ball as a result of the impact,

[2 Marks]

………

………

A2.9 The magnitude of the resultant average force acting on the ball during impact if it is in contact with the floor for 0.10 s.

[2 Marks]

………

………

Reference: AQA Legacy Examination Materials Specimen A

A3. A man jumps from a plane that is travelling horizontally at a speed of 70 m s^{-1}.

If air resistance can be ignored, determine

A3.1 his horizontal velocity 2.0 s after jumping,

[1 Mark]

....

....

A3.2 his vertical velocity 2.0 s after jumping,

[2 Marks]

....

....

....

....

A3.3 the magnitude and direction of his resultant velocity 2.0 s after jumping.

[2 Marks]

....

....

....

....

After 2.0 s the man opens his parachute. Air resistance is no longer negligible. Explain in terms of Newton's laws of motion, why

A3.4 his velocity initially decreases,

[2 Marks]

....

....

A3.5 a terminal velocity is reached.

[2 Marks]

....

....

Reference: AQA Legacy Examination Materials Specimen A

TOPIC: 3.4.1.4 Projectile Motion
SPEC CHECK

Specification	Completed?
Independent effect of motion in horizontal and vertical directions of a uniform gravitational field. Problems will be solvable using the equations of uniform acceleration.	
Qualitative treatment of friction. Distinctions between static and dynamic friction will not be tested.	
Qualitative treatment of lift and drag forces.	
Terminal speed.	
Knowledge that air resistance increases with speed.	
Qualitative understanding of the effect of air resistance on the trajectory of a projectile and on the factors that affect the maximum speed of a vehicle.	
Investigation of the factors that determine the motion of an object through a fluid.	

NOTES

These notes are brief.

More detailed notes are found in the student preparatory reading book.

Please read the preparatory reading notes.

Acceleration Due to Gravity

An object that falls freely will accelerate towards the Earth because of the force of gravity acting on it.

The size of this acceleration does not depend mass, so a feather and a bowling ball accelerate at the same rate. On the Moon they hit the ground at the same time, on Earth the resistance of the air slows the feather more than the bowling ball.

The size of the gravitational field affects the magnitude of the acceleration. Near the surface of the Earth the gravitational field strength is 9.81 N/kg. This is also the acceleration a free falling object would have on Earth. In the equations of motion ***a*** **=** ***g*** **= 9.81 m/s.**

Mass is a property that tells us how much matter it is made of.

Mass is measured in kilograms, kg

Weight is a force caused by gravity acting on a mass:

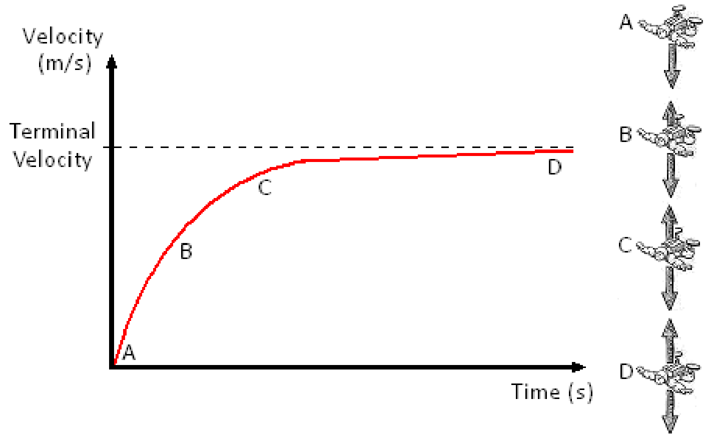
weight = mass x gravitational field strength

$$w = mg$$

Weight is measured in Newtons, N

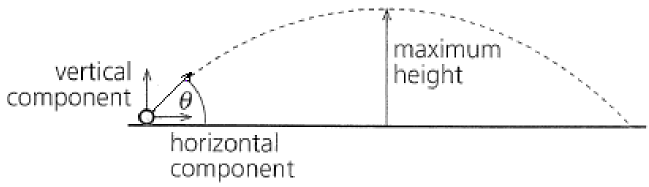
Terminal Velocity

If an object is pushed out of a plane it will accelerate towards the ground because of its weight (due to the Earth's gravity). Its velocity will increase as it falls but as it does, so does the drag forces acting on the object (air resistance). Eventually the air resistance will balance the weight of the object. This means there will be no overall force which means there will be no acceleration. The object stops accelerating and has reached its terminal velocity.



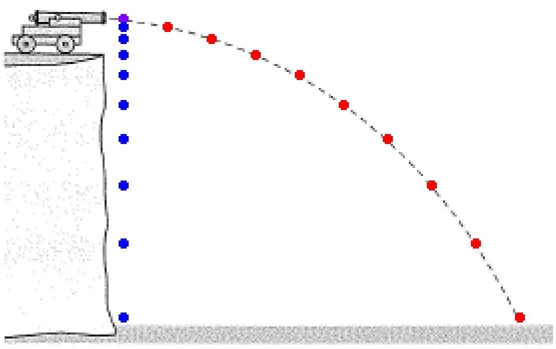
Projectiles

An object kicked or thrown into the air will follow a parabolic path like shown below.
If the object had an initial velocity of u, this can be resolved into its horizontal and vertical velocity The horizontal velocity will be $u\cos\theta$ and the vertical velocity will be $u\sin\theta$. With these we can solve projectile questions using the equations of motion we already know.



Horizontal and Vertical Motion

The diagram shows two balls that are released at the same time, one is released and the other has a horizontal velocity. We see that the ball shot from the cannon falls at the same rate at the ball that was released. This is because the horizontal and vertical components of motion are independent of each other.



Horizontal: The horizontal velocity is constant; we see that the fired ball covers the same horizontal (across) distance with each second.

Vertical: The vertical velocity accelerates at a rate of g (9.81m/s^2). We can see this more clearly in the released ball; it covers more distance each second.

The horizontal velocity has no effect on the vertical velocity. If a ball were fired from the cannon at a high horizontal velocity it would travel further but still take the same time to reach the ground.

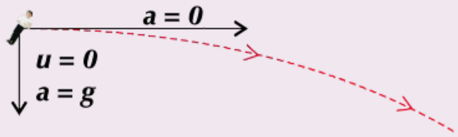
REVISION SHEET

Highlight or underline the key information on the revision sheet to consolidate your understanding.

*You have to think of **Horizontal** and **Vertical** Motion **Separately***

In projectiles, the **horizontal** and **vertical** components of the object's motion are **completely independent**. Projectiles follow a **curved path** because the horizontal velocity remains **constant**, while the vertical velocity is affected by the **acceleration due to gravity**, g.

Example: Jane fires a scale model of a TV talent show presenter horizontally from 1.5 m above the ground with a velocity of 100 ms⁻¹ (to 2 s.f.). How long does it take to hit the ground, and how far does it travel horizontally? Assume the model acts as a particle, the ground is horizontal and there's no air resistance.



Think about vertical motion first:

1) It's **constant acceleration** under gravity...
2) You know $u = 0$ (no vertical velocity at first), $s = -1.5$ m and $a = g = -9.81$ ms^{-2}. You need to find t.
3) Use $s = \frac{1}{2}gt^2 \Rightarrow t = \sqrt{\frac{2s}{g}} = \sqrt{\frac{2 \times -1.5}{-9.81}} = 0.553...$ s. So the model hits the ground after **0.55 (to 2 s.f.)** seconds.

Then do the horizontal motion:

1) The horizontal motion isn't affected by gravity or any other force, so it moves at a **constant speed**. That means you can just use good old **speed = distance / time**.
2) Now $v_h = 100$ ms^{-1}, $t = 0.553...$ s and $a = 0$. You need to find s_h.
3) $s_h = v_h t = 100 \times 0.553... =$ **55 m (to 2 s.f.)**

Where v_h is the horizontal velocity, and s_h is the horizontal distance travelled (rather than the height fallen).

*It's **Slightly Trickier** if it **Starts Off** at an **Angle***

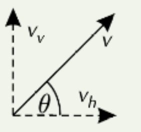
If something's projected at an **angle** (e.g. a javelin) you'll start with **horizontal** and **vertical velocity**. Here's what to do:

1) **Resolve** the initial velocity into **horizontal** and **vertical** components:
2) Often you'll use the vertical component to work out **how long** it's in the air and/or **how high** it goes, and the horizontal component to work out **how far** it goes while it's in the air.

If an object has velocity v, at an angle of θ to the horizontal:

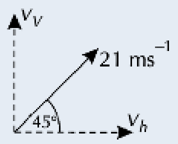
The horizontal component of its velocity is: $v_h = v\cos\theta$

The vertical component of its velocity is: $v_v = v\sin\theta$

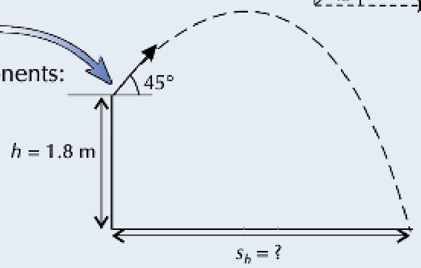


(see page 15)

Example: An athlete throws a javelin from a height of 1.8 m with a velocity of 21 ms⁻¹ at an upward angle of 45° to the ground. How far is the javelin thrown? Assume the javelin acts as a particle, the ground is horizontal and there is no air resistance.



1) Draw a quick sketch of the information given in the question.
2) Start by resolving the velocity into horizontal and vertical components:
   $u_h = \cos 45° \times 21 = 14.84...$ ms^{-1}
   $u_v = \sin 45° \times 21 = 14.84...$ ms^{-1}



3) Then find how long it's in the air for — start by finding v_v. The javelin starts from a height of 1.8 m and finishes at ground level, so its final vertical distance $s_v = -1.8$ m:

   $v_v^2 = u_v^2 + 2gs$

   $v_v = \sqrt{14.84...^2 + 2 \times (-9.81) \times (-1.8)} = -15.99...$ ms^{-1}

   You need the negative square root, as this is a velocity towards the ground.

   Now you can use this v_v value and $s = \frac{(u+v)t}{2}$ to find the time it stays in the air:

   $s_v = \frac{(u_v + v_v)t}{2} \Rightarrow t = \frac{s_v}{(u_v + v_v)} \times 2 = \frac{-1.8}{14.84... - 15.99...} \times 2 = 3.144...$ s

4) Finally, as $a_h = 0$, you can use **speed = distance / time** to work out how far it travels horizontally in this time. The horizontal velocity is just u_h, so: $s_h = u_h t = 14.84... \times 3.144... = 46.68... =$ **47 m (to 2 s.f.)**

You can Investigate Projectile Motion Using a ***Video Camera...***

If you **video** a projectile moving, you can use **video analysis software** to investigate its motion:

1) You can **plot the course** taken by an object by recording its **position** in **each frame**.
2) If you know the **frame rate**, and your video includes a metre ruler or grid lines that you can use as a scale, you can calculate the **velocity** of the projectile between **different points** in its motion, by looking at how far it travels **between frames**.

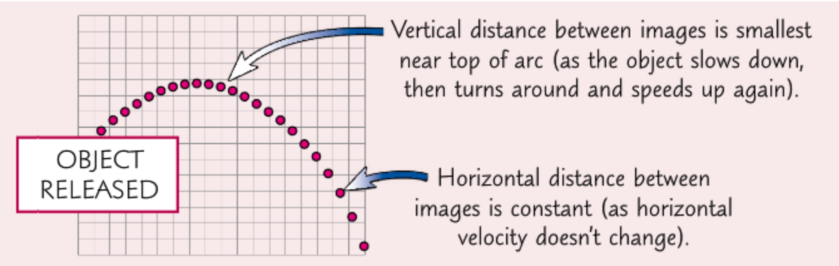
A video camera records a series of pictures, or frames (typically around 25 frames per second). Video analysis software lets you view videos frame by frame.

... or ***Strobe Photography***

In strobe photography, a camera is set to take a **long exposure**. While the camera is taking the photo, a **strobe light** flashes repeatedly and the projectile is released. The strobe light **lights up** the projectile at regular intervals. This means that the projectile appears **multiple times** in the same photograph, in a **different position** each time.

Again, if you've got a **reference object** in the photo (for example, you might throw an object in front of a **screen** with a **grid** drawn on it), you can calculate **how far** the object travels **between flashes** of the strobe, and use the **time** between flashes to calculate the **velocity** of the projectile between the flashes.

The motion of a typical projectile captured with strobe photography is shown below.



Strobe photography and video cameras give you more information than using light-gates to study an object's projectile motion. They can be used whatever the size of the object, unlike a light-gate.

Reference: CGP Revision Guide

Additional Note Space

Additional Note Space

PUZZLES

To improve your understanding, answer the following puzzles.

The answers are overleaf.

QUESTIONS

1 A ball is thrown at an angle of 30° to the horizontal with a velocity of 25 m s^{-1}. Calculate,
(a) the total time of flight;
(b) the horizontal distance the ball travels;
(c) the maximum height reached by the ball.

2 In an archery range an archer can fire arrows with a velocity of 60 m s^{-1}. The target is placed a distance of 50 m away and at the same height. At what angle to the horizontal must the archer aim to strike the target? In order to obtain this angle, he must aim at a point above the target. How high is this point above the target?

3 A holiday-maker leaves his car at the top of a cliff. The brakes suddenly fail and the car accelerates to the cliff edge and runs over the edge with a horizontal velocity of 26 m s^{-1}. If the car strikes the horizontal shoreline 80 m from the base of the cliff, how high is the cliff?

4 In a laboratory oscilloscope, the electrons leave the electron gun with a horizontal velocity of 2×10^7 m s^{-1}. If the screen of the oscilloscope is 30 cm from the gun, how far below the centre of the screen do the electrons strike?

5 A stunt motorcyclist rides his motor cycle up a ramp 5° to the horizontal with a velocity of 39 m s^{-1}. How far away can he place a similar ramp to ensure that he lands on the ramp?

Answering Space

ANSWERS

1 (a) 2.5(5) s; (b) 55 m; (c) 8.0 m

2 3.9°; 3.4 m

3 46 m

4 1.1×10^{-15} m

5 27 m

SAMPLE QUESTION

Q1. Figure 1 shows a skier descending the ramp of a ski jump. **Figure 2** shows a graph of the distance travelled along the ramp against time, from the time the descent starts until the skier leaves the end of the ramp.

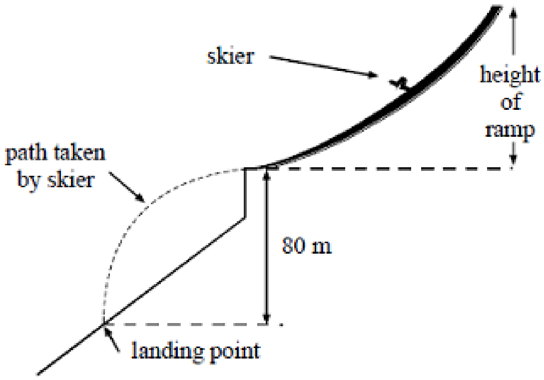


Figure 1

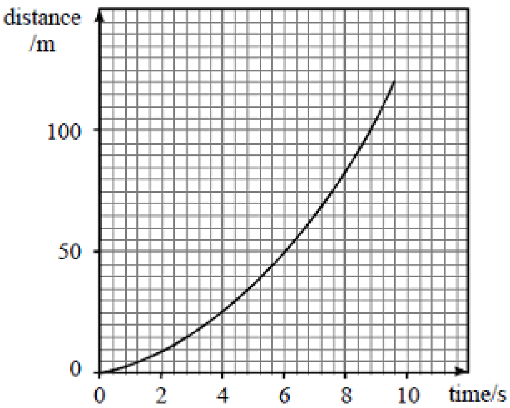


Figure 2

The skier of mass 80 kg (including equipment) skis down the ramp and leaves it horizontally. The skier gains 55% of the available gravitational potential energy as kinetic energy when descending the ramp.

acceleration of free fall, $g = 9.8\ \text{m s}^{-2}$

Q1.1 One energy transformation which occurs as the skier skis down the ramp is from gravitational potential energy to kinetic energy of the skier. State **two** other energy transformations that occur as the skier skis down the ramp.

(kinetic) energy of air / snow (pushing it out of the way)

1 mark

melting / internal energy of snow / ice
or internal energy of air / skis (condone heat)

1 mark
(2)

Q1.2 Use **Figure 2** to show that the speed at which the skier leaves the ramp is about 23 m s^{-1}. Show your reasoning clearly.

(2)

clear attempt to draw tangent to graph at end of run

1 mark

correct co-ordinates and manipulation for tangent
or use of 2 points on curve ≥ t = 7s

1 mark

Q1.3 Determine the height of the ramp.

(3)

potential energy loss = 100 / 55 × KE

1 mark

final KE = 0.5 × m × 23^2

or

equates any KE to mgh

1 mark

height = 49 m allow e.c.f. from (ii)

1 mark

Figure 1 shows the path taken by the skier after leaving the ramp.
Assuming that there was no lift or drag due to the air during this jump, calculate:

Q1.4 the time for which the skier was in flight;

(2)

$s = \frac{1}{2} at^2$ **or** $s = ut + \frac{1}{2}at^2$

1 mark

4.0 s or 4.04 s

1 mark

Q1.5 the horizontal distance jumped by the skier before landing.

(2)

$s = vt$ **or numerical equivalent**

1 mark

92 m – 93 m

1 mark

Q1.6 On landing the skier has considerable vertical momentum that has to be reduced to zero. The surface on which the skier lands is hard-packed snow. To reduce the force experienced by the skier, the landing surface is angled at 40° to the horizontal.

Explain briefly how angling the landing surface reduces the vertical component of the force, experienced by the skier.

force is lower because $F = \frac{\Delta(mv)}{t}$

1 mark

skier has vertical momentum after landing

1 mark

change in momentum is reduced

1 mark

or

$F = \frac{\Delta(mv)}{t}$

1 mark

skier takes longer time to reduce (vertical) momentum

1 mark

compare with time when surface is flat

1 mark

(3)
(Total 14 marks)

Reference: AQA Legacy Examination Materials Specimen B

SELF ASSESSMENT

A1. A ball is dropped and rebounds vertically to less than the original height.

For this first bounce only, sketch graphs of

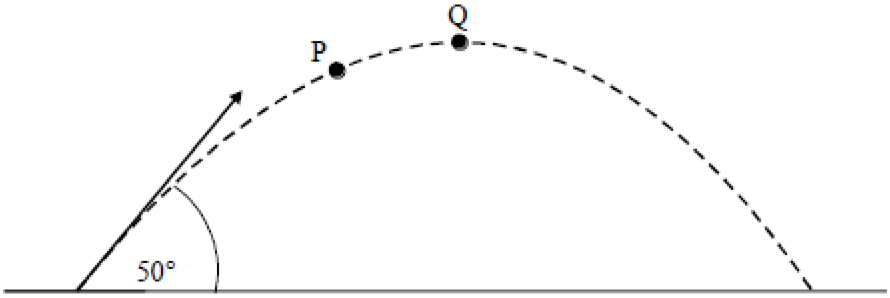
A1.1 the velocity of the ball plotted against time,

[4 Marks]

A1.2 the acceleration of the ball plotted against time.

[1 Mark]

A1.3



The ball is then thrown at an angle to the horizontal and follows the trajectory shown in the diagram.

Mark on the diagram the directions of

[4 Marks]

(i) the acceleration vector at **P**,

(ii) the acceleration vector at **Q**,

(iii) the momentum vector at **P**,

(iv) the momentum vector at **Q**.

A1.4 The mass of the ball is 0.15 kg and the initial direction makes an angle of 50° to the horizontal. Calculate the magnitude of the momentum of the ball at **Q** when it is projected with an initial speed of 15 m s^{-1}. Neglect the effects of air resistance.

[4 Marks]

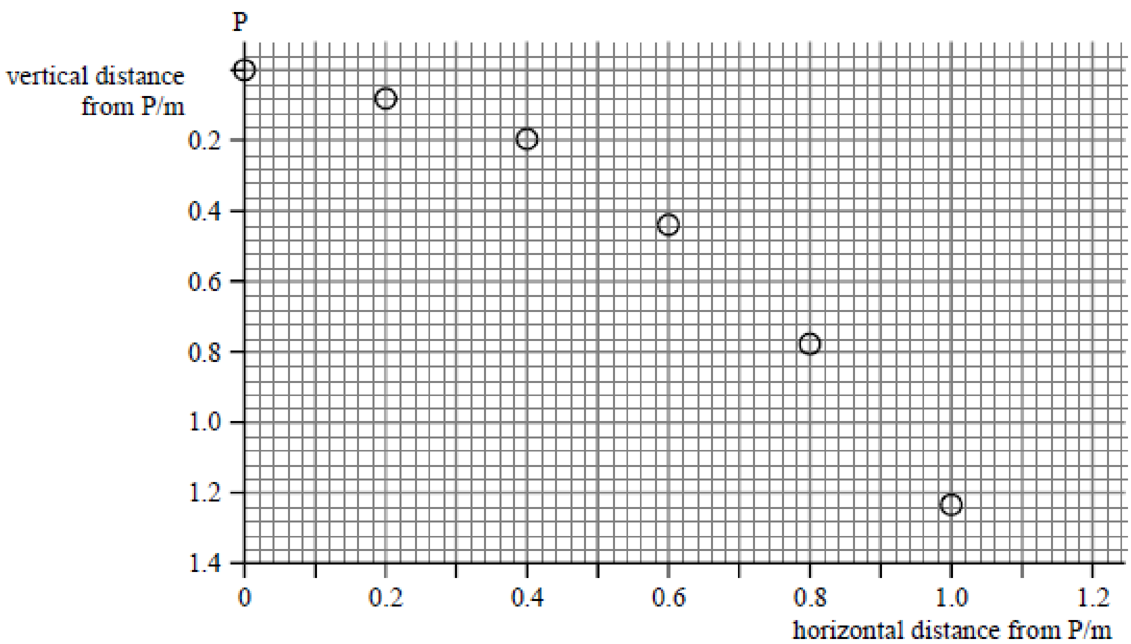
....

....

....

Reference: AQA Legacy Examination Materials Specimen A

A2. The graph shows how the position of a steel ball which has been projected horizontally from P changes with time. The position of the ball is shown at constant time intervals.



A2.1 Explain how the horizontal motion of the ball shows that air resistance is negligible.

[2 Marks]

....

....

....

A2.2 Explain the vertical motion of the ball.

[2 Marks]

....

....

....

....

If air resistance were not negligible, describe how this would affect

A2.3 The horizontal motion of the ball,

[1 Mark]

....

....

A2.4 The vertical motion of the ball.

[2 Marks]

....

....

....

....

Reference: AQA Legacy Examination Materials Specimen A

A3. An electric shower heats the water flowing through it from 10°C to 42°C when the volume flow rate is 5.2×10^{-5} m^3 s^{-1}.

A3.1 Calculate the mass of water flowing through the shower each second.

density of water = 1000 kg m^{-3}

[2 Marks]

....

....

....

....

A3.2 Calculate the power supplied to the shower, assuming all the electrical energy supplied to it is gained by the water as thermal energy.

specific heat capacity of water = 4200 J kg^{-1} K^{-1}.

[2 Marks]

....

....

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....

A3.3 A jet of water emerges horizontally at a speed of 2.5 m s^{-1} from a hole in the shower head. The hole is 2.0 m above the floor of the shower. Calculate the horizontal distance travelled by this jet. Assume air resistance is negligible.

[3 Marks]

....

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....

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Reference: AQA Legacy Examination Materials Specimen A

REVISION CHECKLIST

Specification reference	**Checklist questions**	
3.4.1.1	Can you describe the nature of scalars and vectors, and give examples of each?	☐
3.4.1.1	Can you add vectors by calculation and scale drawing?	☐
3.4.1.1	Can you resolve vectors into two components at right angles to each other, including components of forces along and perpendicular to an inclined plane?	☐
3.4.1.1	Can you solve problems using resolved forces or a closed triangle?	☐
3.4.1.1	Can you describe the conditions for equilibrium for two or three coplanar forces acting at a point?	☐
3.4.1.1	Can you define equilibrium in the context of an object at rest or moving with constant velocity?	☐
3.4.1.2	Can you define the moment of a force about a point as force × perpendicular distance from the point to the line of action of the force?	☐
3.4.1.2	Can you define a couple as a pair of equal and opposite coplanar forces?	☐
3.4.1.2	Can you define the moment of couple as force × perpendicular distance between the lines of action of the forces?	☐
3.4.1.2	Can you explain the principle of moments?	☐
3.4.1.2	Can you describe and define centre of mass?	☐
3.4.1.2	Can you explain that the position of the centre of mass of uniform regular solid is at its centre?	☐

Specification reference	Checklist questions	
3.4.1.3	Can you define displacement, speed, velocity, and acceleration?	☐
3.4.1.3	Can you explain and use the formulae $v = \frac{\Delta s}{\Delta t}$ and $a = \frac{\Delta v}{\Delta t}$?	☐
3.4.1.3	Can you calculate average and instantaneous speeds and velocities?	☐
3.4.1.3	Can you draw a diagram to represent methods of uniform and non-uniform acceleration?	☐
3.4.1.3	Can you explain the significance of areas of velocity–time and acceleration–time graphs, and gradients of displacement–time and velocity–time graphs for uniform and non-uniform acceleration?	☐
3.4.1.3	Can you explain and use the equations for uniform acceleration: $v = u + at$, $s = \left(\frac{u+v}{2}\right)t$, $s = ut + \frac{at^2}{2}$, and $v^2 = u^2 + 2as$?	☐
3.4.1.3	Can you explain acceleration due to gravity, g?	☐
3.4.1.3	Have you carried out a practical to determine g by a freefall method?	☐
3.4.1.4	Can you explain the independent effect of motion in horizontal and vertical directions of a uniform gravitational field?	☐
3.4.1.4	Can you solve problems using the equations of uniform acceleration?	☐
3.4.1.4	Can you define and explain the effects of friction?	☐
3.4.1.4	Can you explain the effects of lift and drag forces?	☐
3.4.1.4	Can you define and describe terminal speed?	☐
3.4.1.4	Can you explain that air resistance increases with speed?	☐
3.4.1.4	Can you explain the effect of air resistance on the trajectory of a projectile and on the factors that affect the maximum speed of a vehicle?	☐

DATASHEET

DATA – FUNDAMENTAL CONSTANTS AND VALUES

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^{8}	$\mathrm{m\ s^{-1}}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\ m^{-1}}$
permittivity of free space	ε_0	8.85×10^{-12}	$\mathrm{F\ m^{-1}}$
magnitude of the charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\mathrm{N\ m^{2}\ kg^{-2}}$
the Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$
molar gas constant	R	8.31	$\mathrm{J\ K^{-1}\ mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{J\ K^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{W\ m^{-2}\ K^{-4}}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4} u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	$\frac{e}{m_e}$	1.76×10^{11}	$\mathrm{C\ kg^{-1}}$
proton rest mass (equivalent to 1.00728 u)	m_p	$1.67(3) \times 10^{-27}$	kg
proton charge/mass ratio	$\frac{e}{m_p}$	9.58×10^{7}	$\mathrm{C\ kg^{-1}}$
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	g	9.81	$\mathrm{N\ kg^{-1}}$
acceleration due to gravity	g	9.81	$\mathrm{m\ s^{-2}}$
atomic mass unit (1u is equivalent to 931.5 MeV)	u	1.661×10^{-27}	kg

ALGEBRAIC EQUATION

quadratic equation $$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

ASTRONOMICAL DATA

Body	Mass/kg	Mean radius/m
Sun	1.99×10^{30}	6.96×10^{8}
Earth	5.97×10^{24}	6.37×10^{6}

GEOMETRICAL EQUATIONS

arc length	$= r\theta$
circumference of circle	$= 2\pi r$
area of circle	$= \pi r^2$
curved surface area of cylinder	$= 2\pi rh$
area of sphere	$= 4\pi r^2$
volume of sphere	$= \frac{4}{3}\pi r^3$

Particle Physics

Class	Name	Symbol	Rest energy/MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	π meson	$\pi^\pm$	139.576
		π^0	134.972
	K meson	$K^\pm$	493.821
		K^0	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks

antiquarks have opposite signs

Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

Properties of Leptons

		Lepton number
Particles:	$e^-, \nu_e; \mu^-, \nu_\mu$	$+1$
Antiparticles:	$e^+, \overline{\nu_e}, \mu^+, \overline{\nu_\mu}$	-1

Photons and energy levels

photon energy $E = hf = hc/\lambda$

photoelectricity $hf = \phi + E_{k\,(max)}$

energy levels $hf = E_1 - E_2$

de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

Waves

wave speed $c = f\lambda$ *period* $f = \frac{1}{T}$

first harmonic $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$

fringe spacing $w = \frac{\lambda D}{s}$ *diffraction grating* $d \sin\theta = n\lambda$

refractive index of a substance s, $n = \frac{c}{c_s}$

for two different substances of refractive indices n_1 *and* n_2,

law of refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2$

critical angle $\sin\theta_c = \frac{n_2}{n_1}$ for $n_1 > n_2$

Mechanics

moments moment $= Fd$

velocity and acceleration $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$

equations of motion $v = u + at$ $s = \left(\frac{u+v}{2}\right)t$

$v^2 = u^2 + 2as$ $s = ut + \frac{at^2}{2}$

force $F = ma$

force $F = \frac{\Delta(mv)}{\Delta t}$

impulse $F\,\Delta t = \Delta(mv)$

work, energy and power $W = F\,s\cos\theta$

$E_k = \frac{1}{2}m v^2$ $\Delta E_p = mg\Delta h$

$P = \frac{\Delta W}{\Delta t}$, $P = Fv$

$efficiency = \frac{useful\ output\ power}{input\ power}$

Materials

density $\rho = \frac{m}{V}$ *Hooke's law* $F = k\,\Delta L$

Young modulus $= \frac{tensile\ stress}{tensile\ strain}$ *tensile stress* $= \frac{F}{A}$ *tensile strain* $= \frac{\Delta L}{L}$

energy stored $E = \frac{1}{2}F\Delta L$

Electricity

current and pd $I = \frac{\Delta Q}{\Delta t}$ $V = \frac{W}{Q}$ $R = \frac{V}{I}$

resistivity $\rho = \frac{RA}{L}$

resistors in series $R_T = R_1 + R_2 + R_3 + \ldots$

resistors in parallel $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$

power $P = VI = I^2R = \frac{V^2}{R}$

emf $\varepsilon = \frac{E}{Q}$ $\varepsilon = I(R + r)$

Circular motion

magnitude of angular speed $\omega = \frac{v}{r}$

$\omega = 2\pi f$

centripetal acceleration $a = \frac{v^2}{r} = \omega^2 r$

centripetal force $F = \frac{mv^2}{r} = m\omega^2 r$

Simple harmonic motion

acceleration $a = -\omega^2 x$

displacement $x = A\cos(\omega t)$

speed $v = \pm\omega\sqrt{(A^2 - x^2)}$

maximum speed $v_{max} = \omega A$

maximum acceleration $a_{max} = \omega^2 A$

for a mass-spring system $T = 2\pi\sqrt{\frac{m}{k}}$

for a simple pendulum $T = 2\pi\sqrt{\frac{l}{g}}$

Thermal physics

energy to change temperature $Q = mc\Delta\theta$

energy to change state $Q = m\,l$

gas law $pV = nRT$

$pV = NkT$

kinetic theory model $pV = \frac{1}{3}N\,m\,(c_{rms})^2$

kinetic energy of gas molecule $\frac{1}{2}m\,(c_{rms})^2 = \frac{3}{2}kT = \frac{3RT}{2N_A}$

Gravitational fields

force between two masses $F = \frac{Gm_1m_2}{r^2}$

gravitational field strength $g = \frac{F}{m}$

magnitude of gravitational field strength in a radial field $g = \frac{GM}{r^2}$

work done $\Delta W = m\Delta V$

gravitational potential $V = -\frac{GM}{r}$

$g = -\frac{\Delta V}{\Delta r}$

Electric fields and capacitors

force between two point charges $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$

force on a charge $F = EQ$

field strength for a uniform field $E = \frac{V}{d}$

work done $\Delta W = Q\Delta V$

field strength for a radial field $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$

electric potential $V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$

$E = \frac{\Delta V}{\Delta r}$

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

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

capacitor energy stored $E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$

capacitor charging $Q = Q_0(1 - e^{-t/RC})$

decay of charge $Q = Q_0e^{-t/RC}$

time constant RC

Magnetic fields

force on a current $F = BIl$

force on a moving charge $F = BQv$

magnetic flux $\Phi = BA$

magnetic flux linkage $N\Phi = BAN\cos\theta$

magnitude of induced emf $\varepsilon = N\dfrac{\Delta\Phi}{\Delta t}$

$N\Phi = BAN\cos\theta$

emf induced in a rotating coil $\varepsilon = BAN\omega\sin\omega t$

alternating current $I_{\text{rms}} = \dfrac{I_0}{\sqrt{2}}$ $V_{\text{rms}} = \dfrac{V_0}{\sqrt{2}}$

transformer equations $\dfrac{N_s}{N_p} = \dfrac{V_s}{V_p}$

$efficiency = \dfrac{I_sV_s}{I_pV_p}$

Nuclear physics

the inverse square law for γ radiation $I = \dfrac{k}{x^2}$

radioactive decay $\dfrac{\Delta N}{\Delta t} = -\lambda N,\ N = N_0e^{-\lambda t}$

activity $A = \lambda N$

half-life $T_{½} = \dfrac{\ln 2}{\lambda}$

nuclear radius $R = R_0A^{1/3}$

energy-mass equation $E = mc^2$

OPTIONS

Astrophysics

1 astronomical unit = 1.50×10^{11} m

1 light year = 9.46×10^{15} m

1 parsec = 206265 AU = 3.08×10^{16} m

= 3.26 light year

Hubble constant, H $= 65\ \text{km s}^{-1}\ \text{Mpc}^{-1}$

$M = \dfrac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$

in normal adjustment $M = \dfrac{f_0}{f_e}$

Rayleigh criterion $\theta \approx \dfrac{\lambda}{D}$

magnitude equation $m - M = 5\log\dfrac{d}{10}$

Wien's law $\lambda_{\max}T = 2.9 \times 10^{-3}\ \text{m K}$

Stefan's law $P = \sigma AT^4$

Schwarzschild radius $R_s \approx \dfrac{2GM}{c^2}$

Doppler shift for v << c $\dfrac{\Delta f}{f} = -\dfrac{\Delta\lambda}{\lambda} = \dfrac{v}{c}$

red shift $z = -\dfrac{v}{c}$

Hubble's law $v = Hd$

Medical physics

lens equations $P = \dfrac{1}{f}$

$m = \dfrac{v}{u}$

$\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$

threshold of hearing $I_0 = 1.0 \times 10^{-12}\ \text{W m}^{-2}$

intensity level $intensity\ level = 10\log\dfrac{I}{I_0}$

absorption $I = I_0e^{-\mu x}$

$\mu_m = \dfrac{\mu}{\rho}$

ultrasound imaging $Z = \rho c$

$\dfrac{I_r}{I_i} = \left(\dfrac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$

half-lives $\dfrac{1}{T_E} = \dfrac{1}{T_B} + \dfrac{1}{T_P}$

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All relevant information has been credited in the document.

This document has been produced for educational purposes only.

This document has been produced for the AQA A Level Physics Specification.

Student Voice

If you when using this document, you believe there is an improvement to made, please state this in the space below….

Only constructive and reasoned feedback will be considered.