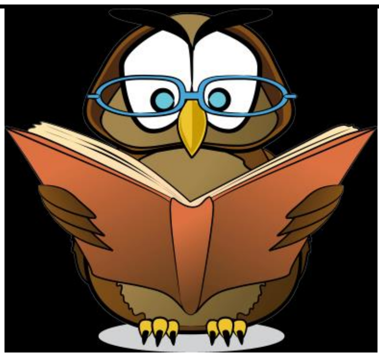


KNOWLEDGE

ST MARY'S SCIENCE DEPARTMENT:

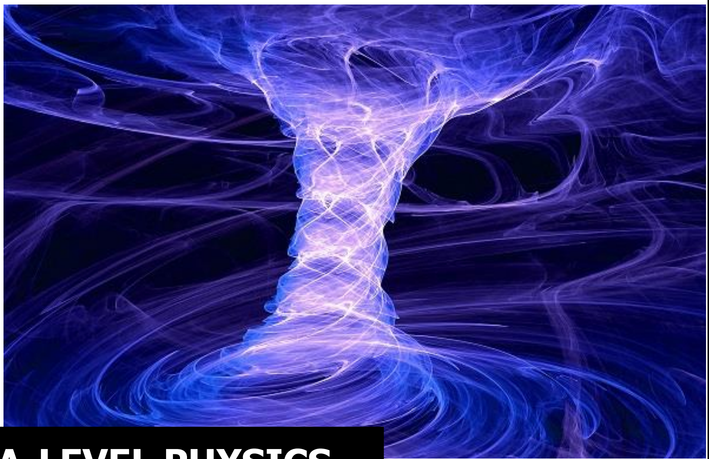
PHYSICS

VERSION 1.1

A LEVEL PHYSICS **YEAR 1**
PREPARATORY READING BOOK
MECHANICS AND MATERIALS

WEEK 4

NAME	
PHYSICS CLASS	



A-LEVEL PHYSICS

TOPIC 4

BRIDGING WORK

THIS MUST BE BROUGHT TO PHYSICS LESSONS AT THE START OF YEAR 12.

Contents

Overview

This bridging course will provide you with a mixture of information about A-level Physics, and what to expect from the course, as well as key work to complete. Students who are expecting to study Physics at A-level, and are likely to meet the entry requirements, must complete the bridging course fully and thoroughly, to the best of their ability.

You should complete all work on paper and keep it in a file, in an ordered way. You will submit it to your teacher in September.

All of the work will be reviewed, and selected work will be assessed, and you will be given feedback on it. This work will be signalled to you. If you do not have access to the internet, please contact the school and appropriate resources will be sent to you.

If you are thinking about studying Physics at A-level, you should attempt this work to see whether or not you think studying a subject like this is right for you. If you later decide to study Physics, you must ensure you complete this work in full.

This work should be completed after you have read and completed the Study Skills work that all of Year 12 should complete.

Course Overview

To successfully achieve a qualification in A-Level Physics students must carry out two years of studies (Year 12 and Year 13) and carry out 3 assessments at the end of the course based on the specification below.

In addition, students must carry out a list of 12 required practical activities that they must carry out. Exam questions will be based on these practicals. 6 practicals will be carried out in Year 12 and 6 practicals will be carried out in Year 13.

If successful, students will receive a practical endorsement along with their A-Level Physics qualification.

First year of A-level

1. Measurements and their errors, including use of SI units and their prefixes, limitations of physical measurement, estimation of physical quantities

2. Particles and radiation, including constituents of the atom, particle interactions, collisions of electrons with atoms.

3. Waves, including progressive waves, interference, diffraction.

4. Mechanics and energy, including projectile motion, Newton's laws of motion.

5. Electricity, including current/ voltage characteristics, circuits, electromotive force and internal resistance.

Second year of A-level

6. Further mechanics and thermal physics, including periodic motion, thermal energy transfer, and molecular kinetic theory model.

7. Fields, including Newton's law of gravitation, orbits of planets and satellites, magnetic flux density.

8. Nuclear physics, including evidence for the nucleus, radioactive decay, nuclear instability.

Plus one option from:

- Astrophysics, including classification of stars by luminosity, Doppler Effect, detection of exoplanets.
- Medical physics, including physics of vision, ECG machines, x-ray imaging.
- Engineering physics, including rotational dynamics, thermodynamics, and engines.
- Turning points in physics, including discovery of the electron, Einstein's theory of special relativity.
- Electronics, including discrete semiconductor devices, data communication systems.

Assessment Schedule

To gain a qualification in A Level Physics – you must sit **three** examinations.

Paper 1	+ Paper 2	+ Paper 3
Content • Topics 1 – 5 • and periodic motion	**Content** • Topics 6 – 8	**Content** • Practical skills • Data analysis • Optional topic
Assessment • Written exam: 2 hours • 85 marks • 34% of A-level	**Assessment** • Written exam: 2 hours • 85 marks • 34% of A-level	**Assessment** • Written exam: 2 hours • 80 marks • 32% of A-level
Questions • 60 marks: a mixture of short and long answer questions • 25 marks: multiple choice questions	**Questions** • 60 marks: a mixture of short and long answer questions • 25 marks: multiple choice questions	**Questions** • 45 marks: questions on practical experiments and data analysis • 35 marks: questions on optional topic

The marks awarded on the papers will be scaled to meet the weighting of the components.

Students' final marks will be calculated by adding together the scaled marks for each component. Grade boundaries will be set using this total scaled mark. The scaling and total scaled marks are shown in the table below.

Component	Maximum raw mark	Scaling factor	Maximum scaled mark
Paper 1	85	x1	85
Paper 2	85	x1	85
Paper 3: Section A	45	x1	45
Paper 3: Section B (Astrophysics – option)	35	x1	35
Paper 3: Section B (Medical physics – option)	35	x1	35
Paper 3: Section B (Engineering physics – option)	35	x1	35
Paper 3: Section B (Turning points in physics – option)	35	x1	35
Paper 3: Section B (Electronics – option)	35	x1	35
		Total scaled mark:	250

Aim

In this bridging course, we will outline the basic principles of the four key topics covered in Year 12 Physics.

In each topic, we will start by reviewing the understanding which you gained in GCSE Physics and apply it to more advanced applications found in A-Level Physics.

This is not a comprehensive overview of the A-Level Physics specification, rather a taster on what is covered throughout the course.

This bridging course should give you an experience of the level you will be expected to study at, at the start of Year 12

Important

Please remember to look after your own wellbeing as you work through this bridging course.

Please take regular breaks as you go through this work.

This work should take approximately 5 hours, so should not be completed in one sitting.

Do not worry or panic if there is something challenging or which you do not understand at first. This is completely normal.

If you do not understand a concept after reviewing this work, please contact Mr. Turnbull on his school e-mail address.

WEEK 4: Mechanics

RECAP TASK

In the previous week, we looked at key concepts in Electricity.

This included looking at the basics of electricity, current-potential difference characteristics and resistivity.

To recap and assess your understanding, answer the following questions on these topics.

Q1.1 A semiconducting diode is an example of a **non-ohmic** component.

State what is meant by a non-ohmic component.

[1 Mark]

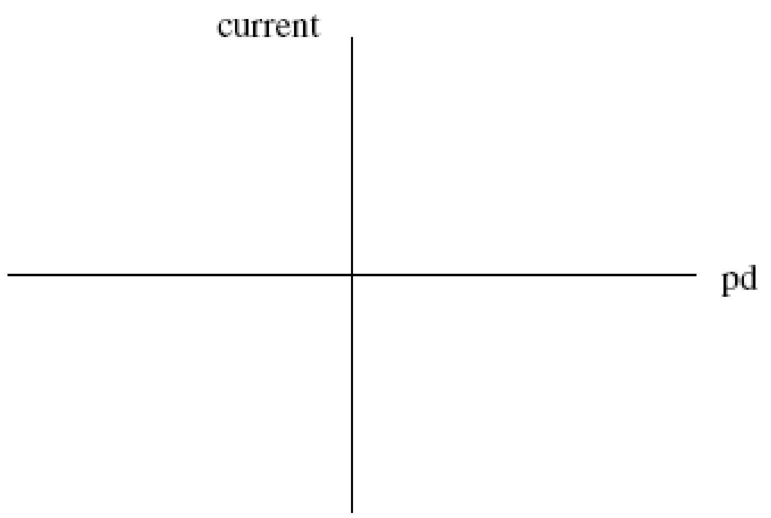
....

....

A filament lamp is also an example of a non-ohmic component.

Q1.2 Sketch on the axes below the current-voltage characteristic for a filament lamp.

[2 Marks]



Q1.3 State, with reference to the current-voltage characteristic you have drawn, how the resistance of the lamp changes as the pd across its terminals changes.

[1 Mark]

....

....

A filament lamp has a power rating of 36 W when there is a pd across its terminals of 12V.

Q1.4 Calculate the resistance of the filament when the pd across its terminals is 12V.

[2 Marks]

....

....

....

....

Answer = ______________________ Ω

Q1.5 A student predicts that if the pd across the bulb is reduced to 6.0 V the power rating of the bulb would be 9.0 W. State and explain how in practice the power rating will be slightly different from this value.

[3 Marks]

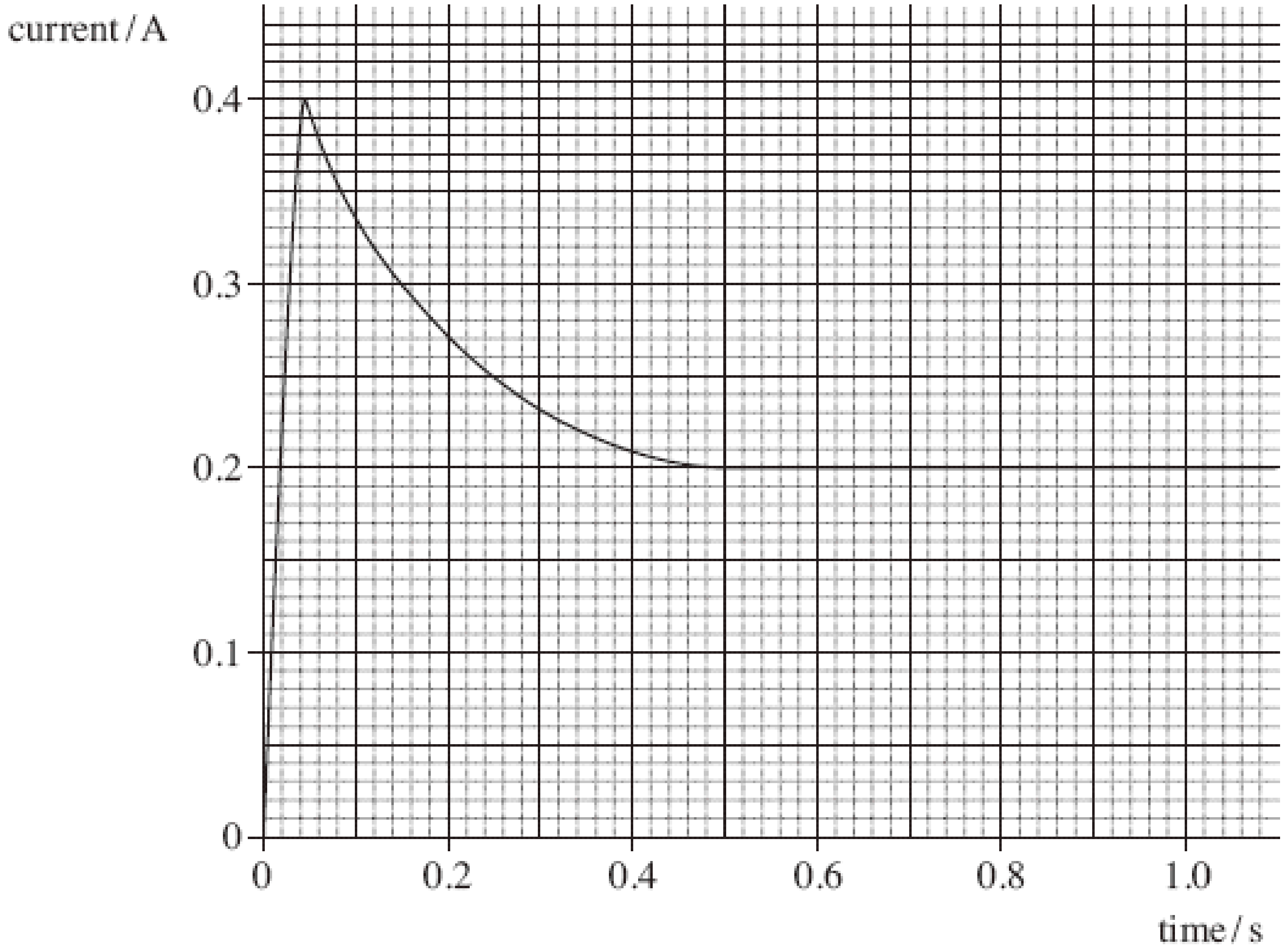
....

....

....

....

Q2. When a filament lamp is switched on it takes 0.50 seconds for the filament to reach its normal operating temperature. The way in which the current changes during the first second after switching on is shown on the graph below.



Q2.1 Use the graph to determine the maximum current through the lamp.

[1 Mark]

....

....

Answer = ______________________ A

Assuming that the lamp is connected to a 12V dc supply of a negligible internal resistance,

Q2.2 Calculate the resistance of the lamp when it has reached its normal operating temperature,

[1 Mark]

....

....

Answer = ______________________ Ω

Q2.3 Calculate the power of the lamp when it has reached its normal operating temperature.

[1 Mark]

....

....

Answer = ______________________ W

Q2.4 Explain why the current through the lamp decreases between 0.05 s and 0.50 s.

[2 Marks]

....

....

....

....

State and explain the change, if any, to the final current through the lamp if it is connected to the same supply with another similar lamp

Q2.5 In series,

[2 Marks]

....

....

....

Q2.6 In parallel.

[2 Marks]

....

....

....

Q2.7 State and explain why a filament lamp is most likely to fail as it is switched on.

[2 Marks]

....

....

....

....

Q3.1 State what is meant by a superconductor.

[2 Marks]

....

....

....

Q3.2 With reference to **two** uses for superconductors in today’s world, explain the advantage of their use compared with conventional conductors such as copper.

[3 Marks]

....

....

....

....

ANSWERS

Q1.1 a non-ohmic conductor does not have a constant resistance **(1)**

1

Q1.2 curve of decreasing gradient with increasing V **(1)**

attempt to make graph symmetric in two opposite quadrants **(1)**

2

Q1.3 resistance **increases** as pd increases/current increases **(1)**

1

Q1.4 (use of $P = V^2/R$)

36 = 144/R **(1)**

R = 4.0 (Ω) **(1)**

2

Q1.5 reference to temperature change **(1)**

(resulting in) a lower resistance **(1)**

(hence) power rating would be greater **(1)**

3

Q2.1 current = 0.40 A **(1)**

1

Q2.2 resistance = 12/0.2 = 60 Ω **(1)**

1

Q2.3 power = 12 × 0.2 = 2.4 W **(1)**

1

Q2.4 resistance of filament increases **or** more collisions/scattering **(1)**

as temperature of filament increase **or** filament gets hot/heats
(until reaches thermal equilibrium) **(1)**

2

Q2.5 voltage of supply now shared by lamps
or resistance increased **(1)**

hence current reduced **(1)**

2

Q2.6 current through the **lamps** unchanged/stays the same **(1)**

as both connected directly to the supply
or correct resistance argument **(1)**

2

Q2.7 resistance of lamps will be lower when first switched on **(1)**

hence initial current will be larger **(1)**

sudden rapid change in temperature **(1)**

max 2

Q3.1 zero resistance

M1

at or below critical/transition temperature

A1
2

Q3.2 one valid use mentioned or reason why important

B1

one valid use with reason why important or two significantly different valid uses

B1

two valid uses with reasons

B1

e.g. **uses**

electromagnet/magnets for accelerators/scanners

generators/transmission lines/electric cables/power

transmission

transformers

computers (reason: increased speed and heating problems)

amplifiers in radio astronomy (reason: low noise)

reasons

can produce extremely high magnetic field strengths

can produce low-energy (power) loss conductors

less energy/power wasted or lower energy loss

3

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.
Displacement	**s**	The distance travelled in a given direction.
Drag force	**F**	The force of fluid resistance on an object moving through the fluid.
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.
Mass	**m**	A measure of inertia or resistance to change of motion of an object.
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.
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.

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)
Weight	$W = m \times g$
Velocity	$v = \frac{\Delta s}{\Delta t}$
Acceleration	$a = \frac{\Delta v}{\Delta t}$
Distance Travelled	$d = v \times t$
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	$v = gt$ $v^2 = 2gs$ $s = \frac{1}{2} gt^2$ $s = vt/2$ **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.

Key Term	Definition
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 Errors	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.
Nominal Variables	A nominal variable is a type of categoric variable where there is no ordering of categories (e.g. red flowers, pink flowers, blue flowers).

IMPORTANT NOTE
These definitions must be memorised by students.

You will be tested on your knowledge of these definitions.

IMPORTANT

A video of Mr. Turnbull going through this book can be found here.

SCAN ME

VIDEO

COURSE OVERVIEW

To watch a video looking at all of the concepts in mechanics, please scan one of the following codes with your smartphone.

Scan me

Note

All rights to this video belong to the creator of the video.

This external third-party content – please check the contents are appropriate.

Scan me

Note

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This external third-party content – please check the contents are appropriate.

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.	

Student Checklist
Complete the following before attempting any work on this section.

Have I…….	**Yes or No?**
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	

Complete the above checklist with the notes of each section before you attempt to answer any questions on this section of work.

Distance

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

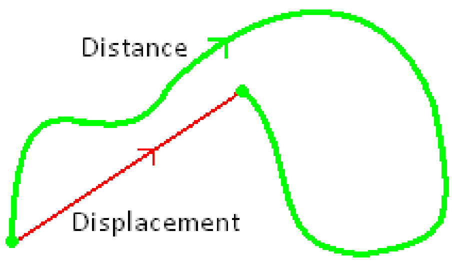
Distance is a scalar quantity. It is a measure of the total length you have moved in a journey.

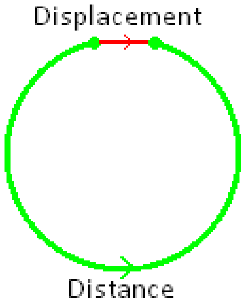
Displacement

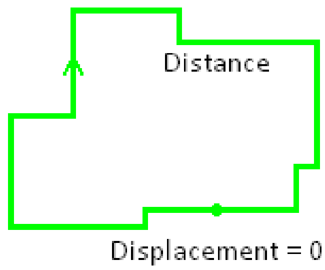
Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

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

Distance and Displacement are measured in metres, m







Speed

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

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

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

Velocity

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

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

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

Study Tip
This topic is common content with the A-Level Mathematics specification.

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

Time is measured in seconds, s

Study Tip

Learn what these equations represents.

The shows the speed and velocity of a moving object.

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Acceleration

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

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 an increase in the velocity

You must consider the situation of the object to determine which answer is correct.

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).

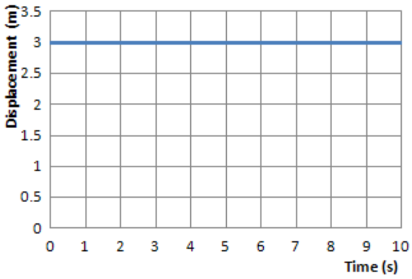
$$gradient = \frac{\Delta y}{\Delta x}$$

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

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**



A

Examination Tip

If a section of a displacement-time graph is horizontal, the object's velocity is zero.

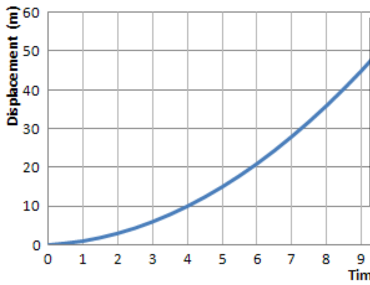
It is not moving.

Study Tip
Always learn what the gradient and area under the line represent on a graph.

B

Examination Tip

A negative gradient would mean the object is moving backwards.



C

Study Tip
This topic is common content with the A-Level Mathematics specification.

Graph A shows that the displacement stays at 3m, it is stationary.
This is shown by a flat line.

Graph B shows that the displacement increases by the same amount each second, it is travelling with constant velocity.
This is shown by a straight line.

Graph C shows that the displacement covered each second increases each second, it is accelerating.
This is given by a curving line.

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

Working Scientifically Link

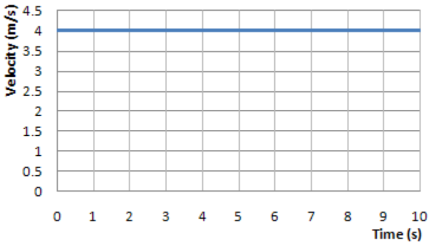
Remember how to determine velocity from this graph.

Working Scientifically Link

Remember if a line is curved, a tangent must be drawn to work out a gradient by drawing the gradient of the tangent.

Velocity- Time Graphs

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**



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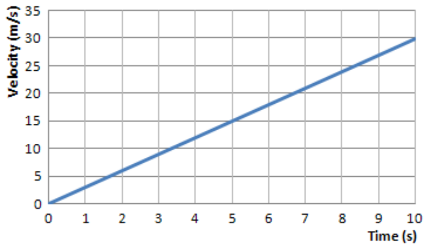

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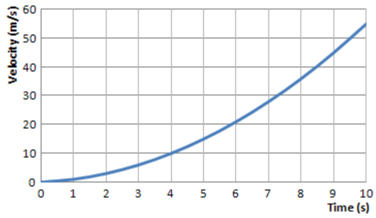


C

Graph A shows that the velocity stays at 4m/s, it is moving with constant velocity.
This is shown by a flat line.

Working Scientifically Link

Remember how to determine displacement and acceleration from this graph.

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

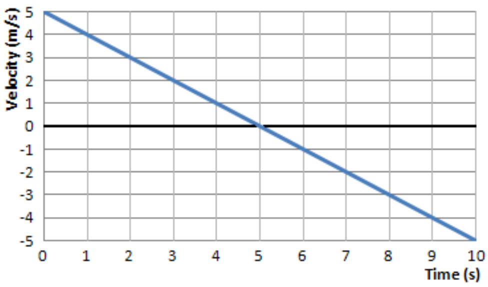
Working Scientifically Link

Remember if a line is curved, a tangent must be drawn to work out a gradient.

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

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

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.

Examination Tip

The areas under any negative parts of the graph count as 'negative areas' as they show the object moving the opposite way to whichever direction you take as positive.

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 ←

Examination Tip

Remember that u is initial velocity and v is final velocity.

Working Scientifically Link

Remember if a line is trending downwards, then the gradient must be a negative value.

Physics Tip

Uniform acceleration and deceleration are shown by a straight line on a velocity-time graph.

Study Tip
This topic is common content with the A-Level Mathematics specification.

Physics Tip

In a velocity-time graph of a bouncing ball, the maximum velocity decreases with each bounce because some of the ball's kinetic energy is transferred into other forms when it hits the ground. This means the height of each bounce also decreases.

Examination Tip

The displacement and distance travelled is the same if there is no negative part on a velocity-time graph.

Examination Tip

Uniform acceleration and deceleration are shown by straight lines on a velocity-time graph.

Examination Tip

If the v-t graph is on a grid, you could also work out the area under the graph by counting how many squares make up the area. Multiplying the value of each square by the number of squares will give you displacement.

Acceleration-Time Graphs

An acceleration-time graph can give you a few values for a journey.

The height of an acceleration-time graph gives you the acceleration of an object that point of the journey.

The area under the line of an acceleration-time graph is the velocity of the object during its journey.

Defining Symbols

Key Topic Warning
This topic is very common for questions on previous A-Level Papers.

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

Examination Tip

These equations are also known as the 'SUVAT' equations.

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

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

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Study Tip

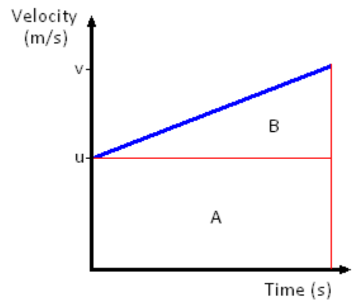
Learn what these equations re\presents.

The shows the motion of an object with constant acceleration.

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

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Study Tip

Learn what these equations re\presents.

The shows the motion of an object with constant acceleration.

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 $s = \frac{1}{2}(u+v)t$

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

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 = $s =$ $ut + \frac{1}{2}(v-u)t$ since $a = \frac{(v-u)}{t}$ then $at = (v-u)$ so the equation becomes $s = ut + \frac{1}{2}(at)t$ which then becomes equation 3

Examination Tip

Deceleration is the same as negative acceleration.

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Study Tip

Learn what these equations re\presents.

The shows the motion of an object with constant acceleration.

Equation 4

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

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

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

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Study Tip

Learn what these equations re\presents.

The shows the motion of an object with constant acceleration.

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.

Study Tip
This topic is common content with the A-Level Mathematics specification.

Examination Tip

Usually you take upwards as the positive direction, however this does not have to be the case.

VIDEO

To watch a video looking at this concept, please scan one of the following codes with your smartphone.

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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:

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

where:
u = initial velocity, a = acceleration
v = final velocity, 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:

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

s = displacement

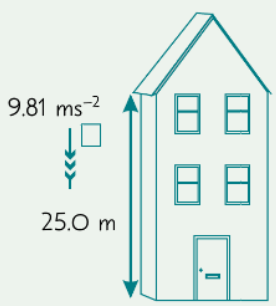
3) Substitute the expression for v from equation 1 into equation 2 to give:

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

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

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: $v^2 = u^2 + 2as$

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:
$a = 2\ ms^{-2}$
$u = 0\ ms^{-1}$

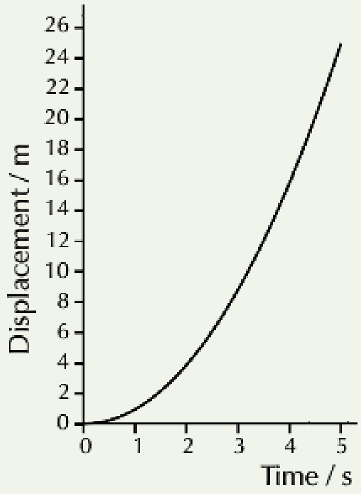
Use $s = ut + \frac{1}{2}at^2$

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**:

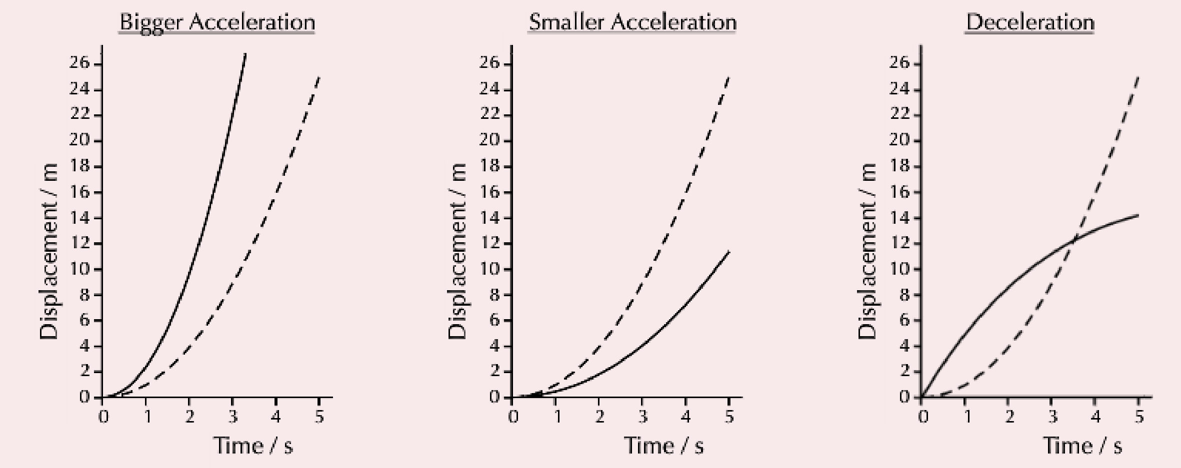
t / s	*s* / m
0	**0**
1	**1**
2	**4**
3	**9**
4	**16**
5	**25**

...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...

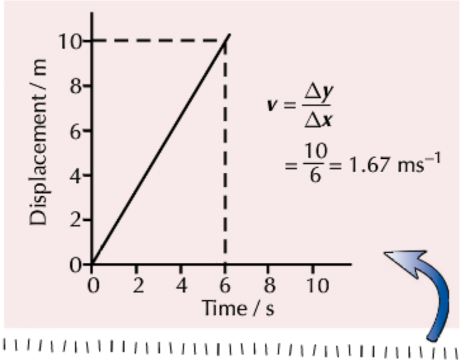
The **Gradient** of a **Displacement-Time Graph** Tells You the Velocity

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.



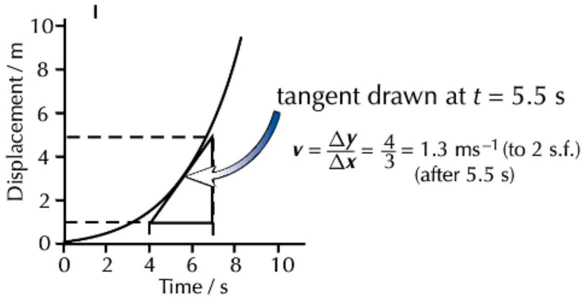
Acceleration is $\frac{\text{change in velocity } (\Delta v)}{\text{change in time } (\Delta t)}$, so it is the rate of change of this gradient. If the gradient is constant (straight line) then there is no acceleration, and if it’s changing (curved line) then there’s acceleration or deceleration.

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.



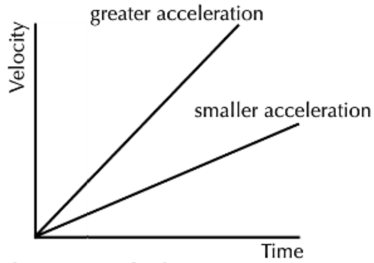
The **Gradient** of a **Velocity-Time Graph** tells you the **Acceleration**

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

likewise for a speed-time graph

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

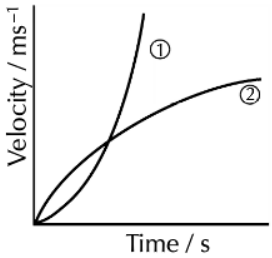
1) **Uniform** acceleration is always a **straight line**.
2) The **steeper** the **gradient**, the **greater** the **acceleration**.



When the **acceleration** is **constant**, you get a **straight-line** v-t graph. The equation for a straight line is $\boldsymbol{y = mx + c}$. You can rearrange the acceleration equation into the same form, getting $\boldsymbol{v = u + at}$.
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

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

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

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**.

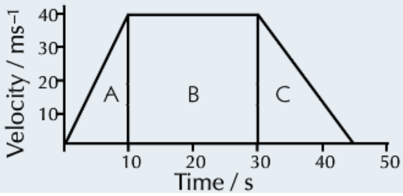
Example: A racing car on a straight track accelerates uniformly from rest to 40 ms^{-1} in 10 s. It maintains this speed for a further 20 s before coming to rest by decelerating at a constant rate over the next 15 s. Draw a velocity-time graph for this journey and use it to calculate the total displacement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

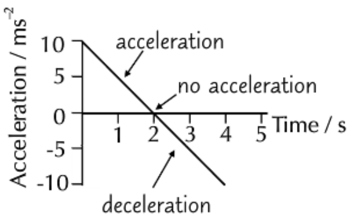


Total displacement = 1300 m

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**.



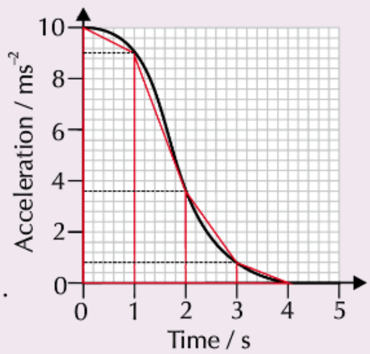
You Have to *Estimate* the Area Under a *Curved* Graph

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 = $\frac{1}{2}$(base × 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

REVIEW QUESTIONS

To assess your understanding, answer the following questions on this topic.

A1. What is the velocity of an object?

[1 Mark]

....

....

A2. What is the acceleration of an object?

[1 Mark]

....

....

A3. What are the 4 SUVAT equations for constant acceleration?

[1 Mark]

....

....

A4. What kind of motion does a curved displacement-time graph show?

[1 Mark]

....

....

A5. What kind of motion does a straight line on a displacement-time graph show?

[1 Mark]

....

....

A6. What does the rate of change of gradient on a displacement-time graph show?

[1 Mark]

....

....

A7. What does the gradient of a velocity-time graph show?

[1 Mark]

....

....

A8. How is uniform acceleration shown on a velocity-time graph?

[1 Mark]

....

....

A9. What does the area under a velocity-time graph tell you?

[1 Mark]

....

....

A10. How would you find velocity from an acceleration-time graph?

[1 Mark]

....

....

The answers to the review questions are found on the next page.

REVIEW ANSWERS

A1. The velocity of an object is its rate of change of displacement.

A2. The acceleration of an object is its rate of change of velocity.

A3. $v = u + at$

$s = (u+v)/2 \times t$

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

$v^2 = u^2 + 2as$

A4. A curved line on a displacement-time graph shows acceleration or deceleration.

A5. A straight line on a displacement-time graph shows constant velocity.

A6. Acceleration.

A7. The gradient of a velocity-time graph shows the acceleration.

A8. Uniform acceleration on a velocity-time graph is shown with a straight line.

A9. The area under a velocity-time graph shows the displacement of the object.

A10. The velocity can be found from an acceleration-time graph as it is the area under the line.

SELF ASSESSMENT

To practice your understanding, answer the following questions.

DO NOT WORRY IF YOU STRUGGLE AT FIRST.

The answers are found after the questions.

Q1. The table below gives test data relating to three types of petrol driven car used commonly on roads in the UK.

car	A	B	C
mass / kg	1250	1340	1610
maximum power / kW	74	81	171
time, in second, taken to accelerate from 0 to 96 km per hour	10.9	12.5	6.9
fuel economy / litre per 100 km	7.7	5.0	9.1
maximum speed / km h^{-1}	187	177	230

Q1.1 Calculate the average acceleration, from rest, of car **A** during the test. Give your answer in m s^{-2}.

[3 Marks]

....

....

....

....

....

Average Acceleration ________________________ m s^{-2}

Q1.2 Calculate the resultant force required to make car **B** accelerate at 2.10 m s^{-2}.

[2 Marks]

....

....

....

Force ________________________ N

Q1.3 Suggest reasons why the data given for car **C** may cause environmental and social concerns.

[3 Marks]

....

....

....

....

....

Reference: AQA A-Level Examination Legacy Materials

Q2. A car is travelling on a level road at a speed of 15.0 m s^{-1} towards a set of traffic lights when the lights turn red. The driver applies the brakes 0.5 s after seeing the lights turn red and stops the car at the traffic lights. The table below shows how the speed of the car changes from when the traffic lights turn red.

time/s	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5
speed/m s^{-1}	15.0	15.0	12.5	10.0	7.5	5.0	2.5	0.0

Q2.1 Draw a graph of speed on the y-axis against time on the x-axis on the grid provided.

[5 Marks]

Q2.2 State and explain what feature of the graph shows that the car's deceleration was uniform.

[2 Marks]

....

....

....

Q2.3 Use your graph to calculate the distance the car travelled after the lights turned red to when it stopped.

[4 Marks]

....

....

....

....

....

....

....

Answer ______________________ m

Reference: AQA A-Level Examination Legacy Materials

ANSWERS

Q1.1 divides a speed (from the table) by 10.9

C1

converts speed to m s^{-1} (26.7)

C1

2.4/2.45/2.5 (m s^{-2})

A1
3

Q1.2 multiples 2.10 by a mass from the table

C1

2810 (N)

A1
2

Q1.3 any two from

Fuel consumption is high

B1

Emissions will also be high

B1

Max speed is very high

B1

any one from

Wasteful of resources

B1

Links high emissions to global warming/specified environmental issue

B1

Road safety implications of high speed

B1
Max 3

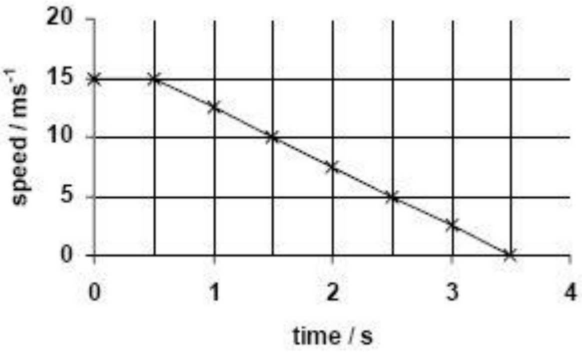
Q2.1 Axes labelled correctly with correct units shown **(1)**

Suitable scales **(1)**

6 points plotted correctly **(1)**

All points plotted correctly **(1)**

Both sections of line drawn correctly **(1)**



5

Q2.2 The gradient (of the slope section) represents the deceleration/ calculates 5 m s^{-2} **(1)**

(deceleration is uniform because) the gradient is constant/ line is straight **(1)**

Q2.3 Distance travelled = area under line (0 to 3.5 s or 0.5 to 3.5 s) **(1)**

(= 15.0 × 0.5) = 7.5 m in first 0.5 s **(1)**

(= 0.5 × 15.0 × 3.0) or s = ½ (u + v)t, etc) = 22.5 m
(from 0.5s to 3.5s) **(1)**

(= ½ (0.5 + 3.5) × 15 gets all three method marks)
(total distance travelled = 7.5 + 22.5) = 30m **(1)**

6
[11]

ASSESSMENT QUESTION

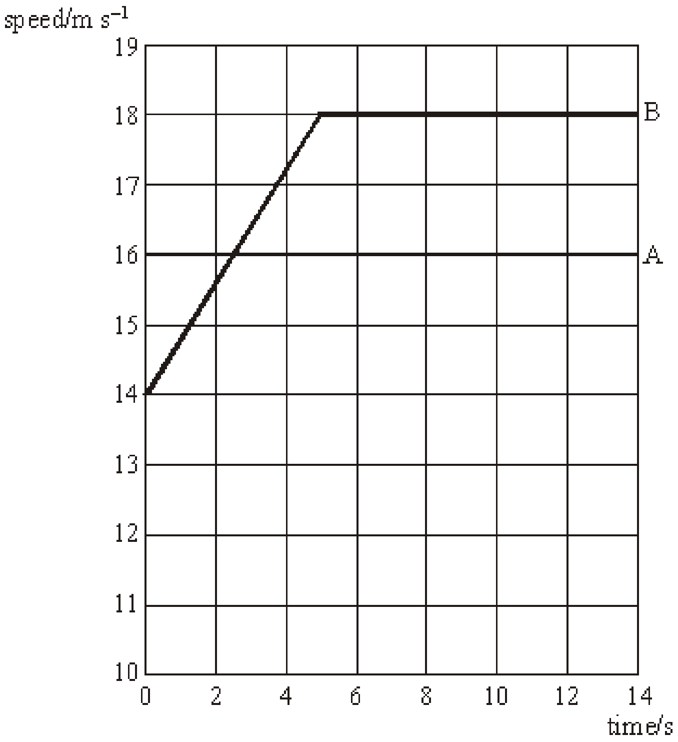
Please answer this assessment question on this topic in Physics.

This work will be formally assessed with feedback given.

This work will be submitted at the start of the A-Level course in Year 12.

If we require any help or you wish to receive immediate feedback, please e-mail Mr. Turnbull.

Q3. The graph represents the motion of two cars, **A** and **B**, as they move along a straight, horizontal road.



Describe the motion of each car as shown on the graph.

Q3.1 car **A**:

[1 Mark]

....

....

Q3.2 car **B**:

[2 Marks]

....

....

....

Calculate the distance travelled by each car during the first 5.0 s.

Q3.3 car **A**:

[2 Marks]

....

....

....

Q3.4 car **B**:

[2 Marks]

....

....

....

Q3.5 At time t = 0, the two cars are level.

Explain why car **A** is at its maximum distance ahead of **B** at t = 2.5 s

[3 Marks]

....

....

....

....

....

Reference: AQA A-Level Examination Legacy Materials

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.	

Student Checklist
Complete the following before attempting any work on this section.

Have I…….	Yes or No?
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	

Complete the above checklist with the notes of each section before you attempt to answer any questions on this section of work.

Acceleration Due to Gravity

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

An object that falls freely will accelerate towards the Earth because of the force of gravity acting on it. This is called freefall.
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.**
In this module, the gravitational field strength is assumed to be constant.
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

Physics Tip

Weight will always act vertically downwards.

It has no horizontal component.

Study Tip

Learn what these equations represents.

The shows the weight of an object.

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Physics Tip

A reaction force is always perpendicular to the surface, and equal in size to the component of the object's weight in the opposite, but parallel direction.

Examination Tip

It is a common examination question to ask how and why the maximum range of a machine on level ground is affected by

- the mass of the user
- the speed at which the machine travels.

Increasing the mass

Reduces the range (1 mark)

increases the friction on the bearings/tyres (1 mark)

OR More energy/power is used accelerating the user to the final speed (1 mark)

OR user and wheelchair have higher KE/ more energy to move (1 mark)

Increasing the speed

Reduces the range (1 mark)

Air resistance increases with speed (1 mark)

We can place the rules of freefall motion into the equations of motion to get the projectile motion equations.

In free fall motion, the initial velocity is zero, so the 'u' term disappears from all equations.

In free fall motion, the acceleration can only be due to gravity (as weight is the only force acting on the object). This means the 'a' term in the equation becomes 'g' (9.81 m/s^2).

This gives the following equations.

$v = gt$

$v^2 = 2gs$

$s = \frac{1}{2} gt^2$

$s = vt / 2$

Physics Tip

An object which only experiences gravity and has no initial velocity is undergoing freefall motion.

An object which only experiences gravity but has an initial velocity is undergoing projectile motion.

These equations represent freefall motion for an object.

Projectile motion is a special case of freefall motion.

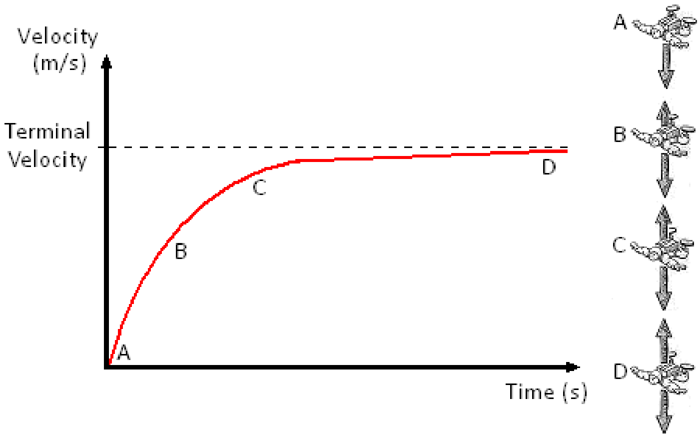
Terminal Velocity

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

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.

Examination Tip

These graphs come up a lot in examinations, make sure you get lots of practice using these graphs.

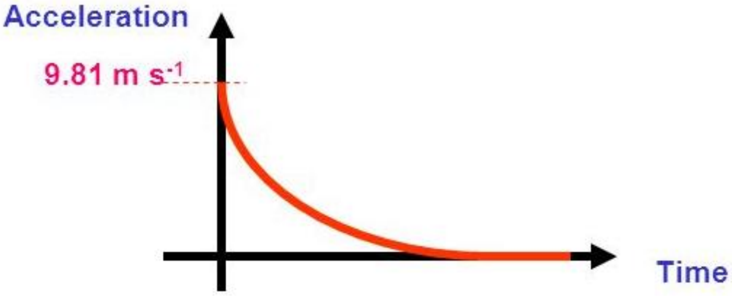


Physics Tip

Falling into water has a similar effect on the velocity of an object as opening a parachute.

Examination Tip

You must be able to correctly sketch an acceleration-time graph for an object in freefall.



Physics Tip

You will probably see both 'terminal speed' and 'terminal velocity' used. In Year 1 Physics, you are likely to be looking at motion in a straight line where the direction is known, so you can talk about terminal speed.

Physics Tip

Remember air resistance on an object increases with speed.

You do not need to know why this is for examinations.

Study Tip
This topic is common content with the A-Level Mathematics specification.

Examination Tip

It is a common examination question explain why the acceleration decreases and eventually reaches zero on a car with constant thrust.

Air resistance increases with speed so resultant force decreases with speed (1 mark)

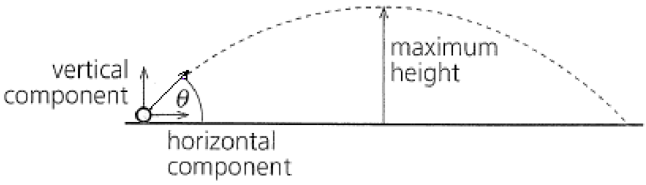
Eventually air resistance = thrust (so no acceleration) (1 mark)

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.

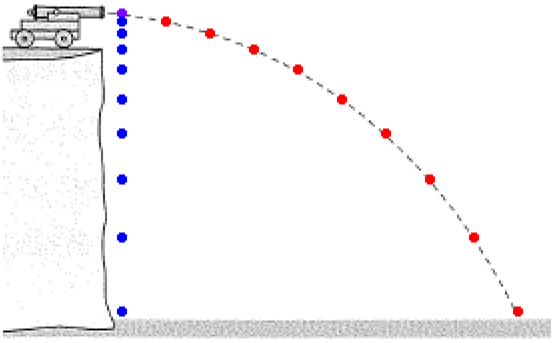
Examination Tip

If you are doing A Level Mathematics, you will also cover projectiles in this course also.



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.
This is because there are no horizontal forces present.
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.
This is because there the only vertical force is weight.
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.

Examination Tip

Assume the object acts as a particle and there is no air resistance means only worry about the effect of weight on the object and nothing else.

Examination Tip

For sake of ease, assume travelling down towards Earth to be negative.

Examination Tip

Denote horizontal velocity with v_h and vertical velocity with v_v.

Denote horizontal displacement with s_h and vertical displacement with s_v.

Examination Tip

In calculations questions, you will be told to ignore air resistance.

However, you must be able to know what effect air resistance would have on the journey of the projectile.

Examination Tip

It is a common examination question explain why air resistance is negligible in the vertical direction

Motion unchanged vertically/ maximum height of P is unchanged: air resistance decelerates P horizontally so less distance travelled. (both points needed) (1 mark).

Air resistance increases with speed: speed is low vertically but very high horizontally (both points needed) (1 mark)

Examination Tip

It is a common examination question explain how the horizontal force on an object has to change for constant acceleration to be maintained.

(forward force would have to) increase (1 mark)

air resistance/drag increases (with speed) (1 mark)

driving/forward force must be greater than resistive/drag force (1 mark)

(So that) resultant/net force stayed the same / otherwise the resultant/net force would decrease (1 mark)

Study Tip
This topic is common content with the A-Level Mathematics specification.

VIDEO

To watch a video looking at this concept, please scan one of the following codes with your smartphone.

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Note

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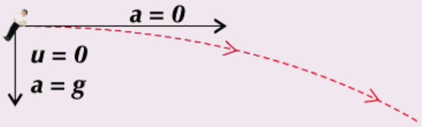
REVISION SHEET

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***

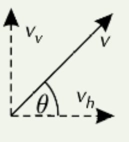
If something's projected at an **angle** (e.g. a javelin) you'll start with **horizontal** and **vertical velocity**. Here's what to do:

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:

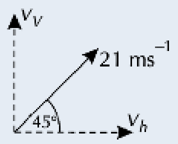
The horizontal component of its velocity is: $v_h = v\cos\theta$

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

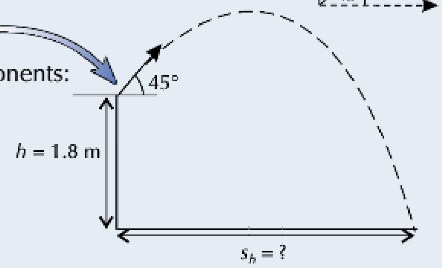


(see page 15)

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**.

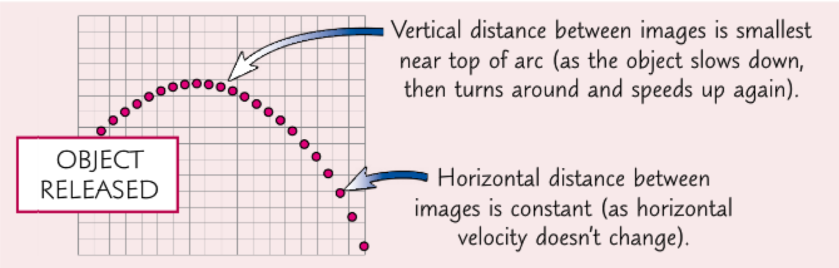
A video camera records a series of pictures, or frames (typically around 25 frames per second). Video analysis software lets you view videos frame by frame.

... 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

REVIEW QUESTIONS

To assess your understanding, answer the following questions on this topic.

A1. What is the only force present in free-fall motion?

[1 Mark]

....

....

A2. Describe an experiment you could do to obtain data that you could use to determine the value of 'g'.

[1 Mark]

....

....

....

....

....

A3. Explain how data could be plotted to determine the value of 'g'.

[1 Mark]

....

....

A4. What is freefall motion called when the object is given an initial velocity?

[1 Mark]

....

....

A5. What should you do if you need to use the equations of uniform acceleration on an object that has an initial velocity at an angle to the horizontal?

[1 Mark]

....

....

A6. What is the effect of air resistance on the trajectory of a projectile?

[1 Mark]

....

....

The answers to the review questions are found on the next page.

REVIEW ANSWERS

A1. The only force present in free fall motion is weight.

A2. Measure the length of time it takes for a metal ball to fall a known distance using a switch to release the ball from an electromagnet and start a timer, and a trap door to catch the ball and stop the timer. Measure the height from the bottom of the ball to the trap door. Flick the switch simultaneously start the timer and disconnect the electromagnet, releasing the ball. The ball will fall, knocking the trapdoor down and breaking the circuit – which stops the timer.
Record the time t shown on the timer.
Repeat this experiment three times and average the time taken to fall from this height. Repeat this experiment but drop the ball from several different heights.

A3. You can plot a graph of height (s) against the time it takes the ball to fall squared (s^2). Then draw a line of best fit and multiply the gradient of the best fit line by two to get a value for g.

A4. Free-fall motion with an initial velocity is called projectile motion.

A5. Resolve the initial velocity into horizontal and vertical components, then use the vertical components to work out how long it is in the air and how high it goes. Then use the horizontal component to work out how far it goes in the horizontal direction while it is in the air.

A6. Air resistance causes a drag force that acts in the opposite direction to motion and affects the trajectory of a projectile. The horizontal component of drag reduces the horizontal distance the projectile can travel. If the projectile has a vertical component of velocity, drag reduces the maximum height the projectile will reach and steepens the angle of descent.

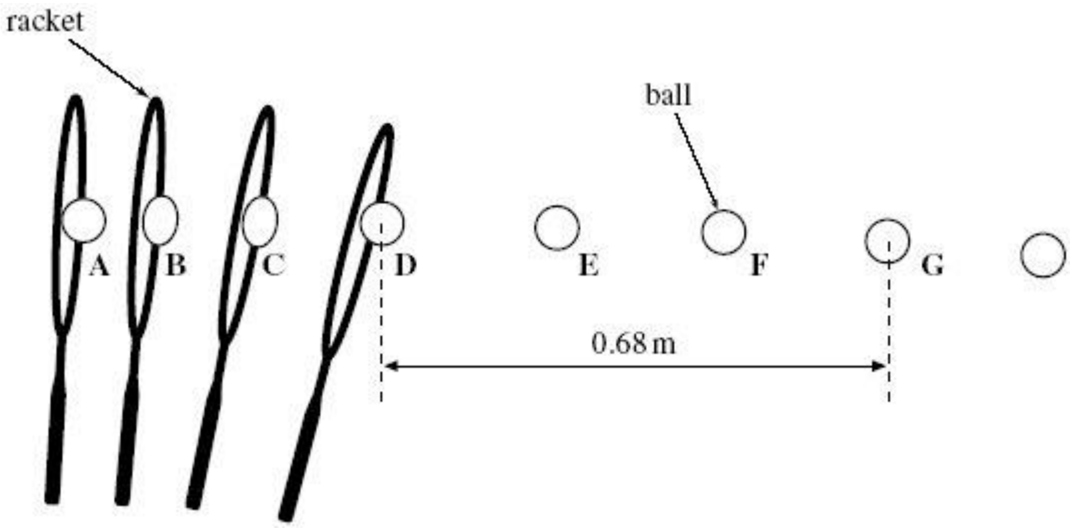
SELF ASSESSMENT

To practice your understanding, answer the following questions.

DO NOT WORRY IF YOU STRUGGLE AT FIRST.

The answers are found after the questions.

Q1. A digital camera was used to obtain a sequence of images of a tennis ball being struck by a tennis racket. The camera was set to take an image every 5.0 ms. The successive positions of the racket and ball are shown in the diagram below.



The ball has a horizontal velocity of zero at **A** and reaches a constant horizontal velocity at **D** as it leaves the racket. The ball travels a horizontal distance of 0.68 m between **D** and **G**.

Q1.1 Show that the horizontal velocity of the ball between positions **D** and **G** in the diagram above is about 45 m s^{-1}.

[3 Marks]

....

....

....

....

....

Q1.2 Calculate the horizontal acceleration of the ball between **A** and **D**.

[1 Mark]

....

....

Answer = ______________________ m s^{-2}

At **D**, the ball was projected horizontally from a height of 2.3 m above level ground.

Q1.3 Show that the ball would fall to the ground in about 0.7 s.

[3 Marks]

....

....

....

....

....

Q1.4 Calculate the horizontal distance that the ball will travel after it leaves the racket before hitting the ground. Assume that only gravity acts on the ball as it falls.

[2 Marks]

....

....

....

....

Answer = ______________________ m

Q1.5 Explain why, in practice, the ball will not travel this far before hitting the ground.

[2 Marks]

....

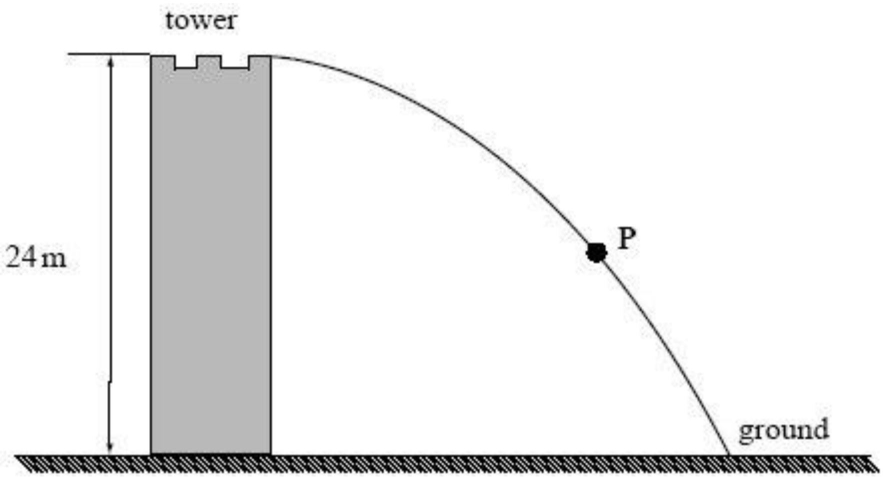
....

....

....

Reference: AQA A-Level Examination Legacy Materials

Q2. The diagram below shows the path of a ball thrown horizontally from the top of a tower of height 24 m which is surrounded by level ground.



Q2.1 Using two labelled arrows, show on the diagram above the direction of the velocity, v, and the acceleration, a, of the ball when it is at point **P**.

[2 Marks]

Q2.2 Calculate the time taken from when the ball is thrown to when it first hits the ground. Assume air resistance is negligible.

[2 Marks]

....

....

....

....

Answer ____________________ s

Q2.3 The ball hits the ground 27 m from the base of the tower. Calculate the speed at which the ball is thrown.

[2 Marks]

....

....

....

....

Answer ____________________ m s^{-1}

Reference: AQA A-Level Examination Legacy Materials

ANSWERS

Q1.1 $v = \frac{s}{t}$ **(1)**

t = 0.015 (s) or 15 (ms) **(1)**

0.68/0.015 **(1)** (= 45)

3

Q1.2 $\left(a = \frac{\Delta u}{\Delta t} = \frac{45.3}{0.015}\right)$ = 3000 (m s^{-2}) (3022) **(1)**

1

Q1.3 $s = (ut) = \frac{1}{2}gt^2$ or $t = \sqrt{\frac{2s}{g}}$ **(1)**

correct substitution seen = $\sqrt{\frac{2 \times 2.3}{9.81}}$ **(1)**

0.68 to 0.69 correct answer to more than one dp seen **(1)**

3

Q1.4 ($s = vt$) = 45(.3) × 0.685 or 0.7 **(1)**

= 30.6 to 32 **(1)** (m)

2

Q1.5 mention of air resistance or drag **(1)**

causing **horizontal** deceleration or 'slowing down' **(1)**

2
[11]

Q2.1 velocity vector tangential to path and drawn from the ball, arrow in correct direction **(1)**

acceleration vector vertically downwards, arrow drawn and in line with ball **(1)**

2

Q2.2 $s = ½ gt^2$ gives $t = \sqrt{\frac{2y}{g}} = \sqrt{\frac{2 \times 24}{9.8(1)}}$ **(1)** = 2.2(1) s **(1)**

Q2.3 v (= s/t) = 27/2.2(1) **(1)** = 12(.2 m s^{-1}) or 12(.3) **(1)** ecf from **Q2.2**

(answer only gets both marks)

4
[6]

ASSESSMENT QUESTION

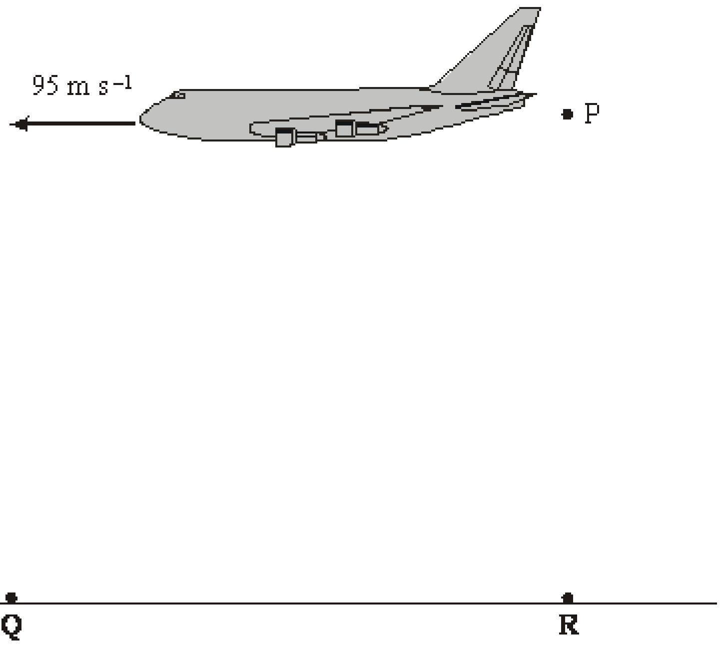
Please answer this assessment question on this topic in Physics.

This work will be formally assessed with feedback given.

This work will be submitted at the start of the A-Level course in Year 12.

If we require any help or you wish to receive immediate feedback, please e-mail Mr. Turnbull.

Q3. The aeroplane 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.



Q3.1 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.

[1 Mark]

Q3.2 Explain why the horizontal component of the crate's velocity remains constant while it is moving through the air.

[2 Marks]

....

....

....

....

Q3.3 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]

....

....

....

....

Q3.4 Calculate the time taken for the crate to reach the ground if the crate is dropped from a height of 52 m.

[2 Marks]

....

....

....

....

Q3.5 If **R** is a point on the ground directly below **P**, calculate the horizontal distance **QR**.

[2 Marks]

....

....

....

....

Q3.6 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 A-Level Examination Legacy Materials

FURTHER READING

You may wish to read around the following topics to further extend your understanding ahead of the start of the course in Year 12.

Newton's Laws of Motion

Scan me

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To watch a video looking at this concept, please scan one of the following codes with your smartphone.

Momentum

Scan me

Scan me

To watch a video looking at this concept, please scan one of the following codes with your smartphone.

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}	$m\ s^{-1}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$H\ m^{-1}$
permittivity of free space	ε_0	8.85×10^{-12}	$F\ m^{-1}$
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}	$N\ m^{2}\ kg^{-2}$
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}
molar gas constant	R	8.31	$J\ K^{-1}\ mol^{-1}$
the Boltzmann constant	k	1.38×10^{-23}	$J\ K^{-1}$
the Stefan constant	σ	5.67×10^{-8}	$W\ m^{-2}\ K^{-4}$
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}	$C\ kg^{-1}$
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}	$C\ kg^{-1}$
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	g	9.81	$N\ kg^{-1}$
acceleration due to gravity	g	9.81	$m\ s^{-2}$
atomic mass unit (1u is equivalent to 931.3 MeV)	u	1.661×10^{-27}	kg

ASTRONOMICAL DATA

Body	Mass/kg	Mean radius/m
Sun	1.99×10^{30}	6.96×10^{8}
Earth	5.98×10^{24}	6.37×10^{6}

GEOMETRICAL EQUATIONS

arc length	$= r\theta$
circumference of circle	$= 2\pi r$
area of circle	$= \pi r^2$
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^-, ν_e ; μ^-, ν_μ	$+1$
Antiparticles:	e^+, $\overline{\nu_e}$, μ^+, $\overline{\nu_\mu}$	-1

Protons 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 $W = Fs\cos\theta$

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

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

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

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

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

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Only constructive and reasoned feedback will be considered.