CGP

Edexcel International GCSE
Physics
For the Grade 9-1 Course

The Revision Guide

For the Physics and Science (Double Award) specifications

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Describing Experiments

Paper 2

This book covers both Physics Paper 1 and Physics Paper 2 material. Some material is needed for Paper 2 only — we've clearly marked this in green boxes.
The Paper 2 revision questions in the book are also printed in green.
If you're doing a Science (Double Award) qualification you don't need to learn the Paper 2 material.

Paper 2

Velocity and Acceleration

Speed and velocity are similar, but in physics they're not quite the same...

Speed and Velocity are Both How Fast You're Going

Speed and velocity both simply say how fast you're going, and both are measured in m/s (or km/h or mph). But there is a subtle difference between them which you need to know:

Speed is just how fast you're going (e.g. 30 mph or 20 m/s) with no regard to the direction. Velocity however must also have the direction specified, e.g. 30 mph north or 20 m/s, 060°.

1) This means you can have objects travelling at a constant speed with a changing velocity. This happens when the object is changing direction whilst staying at the same speed.
2) For any object, the distance moved, (average) speed, and time taken are related by this formula:

You'd use the same formula to calculate velocity.

$$\text{Average speed} = \frac{\text{Distance moved}}{\text{Time taken}}$$

If you're not sure how to use formula triangles, have a look inside the back cover.

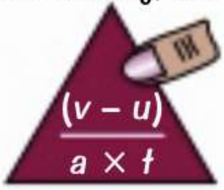
Example: A cat skulks 20 m in 35 s.
Find: a) its average speed, b) how long it takes to skulk 75 m.
Using the formula triangle: a) $v = s/t = 20/35 = \underline{0.57\text{ m/s}}$ (to 2 d.p.)
b) $t = s/v = 75/0.57 = 132\text{ s} = \underline{2\text{ min }12\text{ s}}$

Acceleration is How Quickly Velocity is Changing

1) Acceleration is not the same as velocity or speed. Acceleration is how quickly the velocity is changing.
2) This change in velocity can be a CHANGE IN SPEED or a CHANGE IN DIRECTION or both. You only have to worry about the change in speed bit for calculations.
3) The unit of acceleration is m/s^2. Not m/s, which is velocity, but m/s^2.
4) There are two formulas you need to know:

The formulas for acceleration on this page only work when the acceleration is constant.

① $$\text{Acceleration} = \frac{\text{Change in Velocity}}{\text{Time taken}}$$



Here 'v' is the final velocity and 'u' is the initial velocity.

There's a slightly tricky thing with this formula — the '$(v - u)$' means working out the 'change in velocity', rather than just putting a simple value for velocity or speed in.

A negative value for acceleration means something is slowing down (decelerating).

Example: A skulking cat accelerates from 2 m/s to 6 m/s in 5.6 s. Find its acceleration.
Using the formula triangle: $a = (v - u) / t = (6 - 2) / 5.6 = 4 \div 5.6 = \underline{0.71\text{ m/s}^2}$

② $$v^2 = u^2 + 2as$$

Here 'v' is the final velocity, 'u' is the initial velocity, and 's' is the distance travelled while accelerating.

Example: A van travelling at 23 m/s starts decelerating uniformly at 2.0 m/s² as it heads towards a built-up area 112 m away. What will its speed be when it reaches the built-up area?

1) Put the numbers in — remember a is negative because it's a deceleration. $v^2 = u^2 + (2 \times a \times s)$
$= 23^2 + (2 \times -2.0 \times 112) = 81$
2) Finally, square root the whole thing. $v = \sqrt{81} = \underline{9\text{ m/s}}$

Don't speed through this page — learn it properly...

You might not be told what equation to use in the exam, so make sure you can spot when to use each equation.

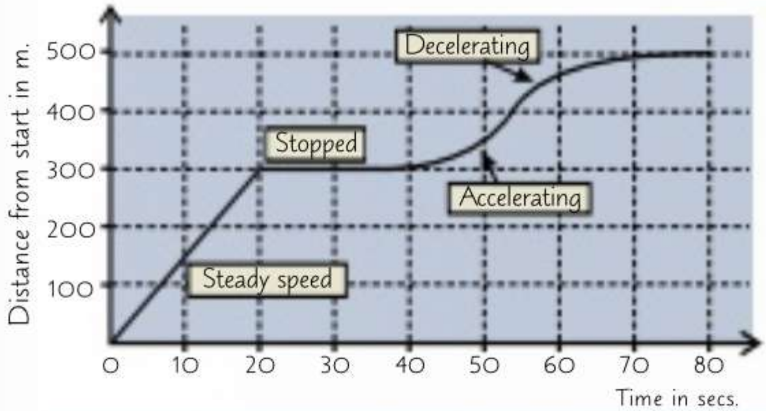
Q1 a) A sprinter runs 200 m in 25 s. Calculate his average speed. [1 mark]
b) As he crosses the line, the sprinter is travelling at the speed in part a).
It then takes him 2 seconds to come to a complete stop. Calculate his acceleration. [2 marks]

Distance-Time and Velocity-Time Graphs

Make sure you learn all these details properly. Make sure you can distinguish between the two, too.

Distance-Time Graphs Tell You *How Far* Something has *Travelled*

The different parts of a distance-time graph describe the motion of an object:



- The gradient (slope) at any point gives the speed of the object.
- Flat sections are where it's stopped.
- A steeper graph means it's going faster.
- Curves represent acceleration.
- A curve getting steeper means it's speeding up (increasing gradient).
- A levelling off curve means it's slowing down (decreasing gradient).

In the above graph, the speed of the first section (between 0 and 20 s) is:

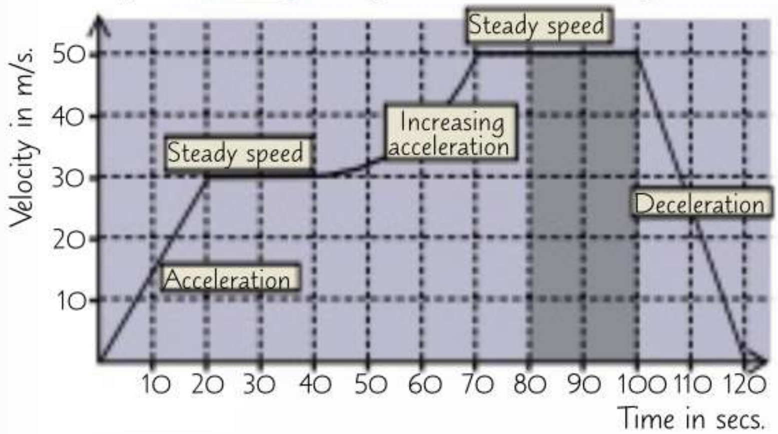
$$\text{Speed} = \text{gradient} = \frac{\text{vertical}}{\text{horizontal}} = \frac{300}{20} = 15 \text{ m/s}$$

Don't forget that you have to use the scales of the axes to work out the gradient. Don't measure in cm!

- You can also calculate the average speed of an object over a period of time by dividing the total distance travelled by the time it takes to travel that distance. For example, the average speed over the whole journey is 500 ÷ 80 = 6.25 m/s

Velocity-Time Graphs can have a Positive or Negative *Gradient*

How an object's velocity changes over time can be plotted on a velocity-time graph.



- Gradient = acceleration.
- Flat sections represent steady speed.
- The steeper the graph, the greater the acceleration or deceleration.
- Uphill sections (/) are acceleration.
- Downhill sections (\) are deceleration.
- The area under any part of the graph is equal to the distance travelled in that time interval.
- A curve means changing acceleration.

1) The acceleration represented by the first section of the graph is:

$$\text{Acceleration} = \text{gradient} = \frac{\text{vertical}}{\text{horizontal}} = \frac{30}{20} = 1.5 \text{ m/s}^2$$

2) The speed at any point is simply found by reading the value off the velocity axis.

3) The distance travelled in any time interval is equal to the area under the graph.

The distance travelled between $t = 80$ s and $t = 100$ s is equal to the shaded area, which is equal to 50 m/s × 20 s = 1000 m

Some maths — oh good...

For practice, try sketching distance-time graphs for different scenarios. Like walking home or running from a bear.

Q1 Sketch a distance-time graph for an object that initially accelerates, then travels at a constant speed, then decelerates to a stop. [2 marks]

Mass, Weight and Gravity

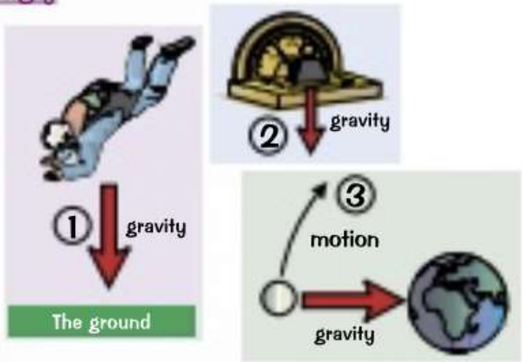
he information on this page may come as a surprise, but it's true — mass and weight are NOT the ame thing. You need to learn about gravity first, then you'll appreciate the differences...

Gravity is the *Force of Attraction* Between *All Masses*

Gravity attracts all masses, but you only notice it when one of the masses is really really big, e.g. a planet. Anything near a planet or star is attracted to it very strongly.

This has three important effects:

1) On the surface of a planet, it makes all things accelerate towards the ground (all with the same acceleration, *g*, which is about 10 m/s² on Earth).
2) It gives everything a weight.
3) It keeps planets, moons and satellites in their orbits. The orbit is a balance between the forward motion of the object and the force of gravity pulling it inwards (see page 74).



Weight and *Mass* are *Not the Same*

To understand this you must learn all these facts about mass and weight:

1) Mass is just the amount of 'stuff' in an object. For any given object this will have the same value anywhere in the universe.
2) Weight is caused by the pull of gravity. In most questions the weight of an object is just the force of gravity pulling it towards the centre of the Earth.
3) An object has the same mass whether it's on Earth or on the Moon — but its weight will be different. A 1 kg mass will weigh less on the Moon (about 1.6 N) than it does on Earth (about 10 N), simply because the force of gravity pulling on it is less.
4) Weight is a force measured in newtons. It's measured using a spring balance or newton meter. Mass is not a force. It's measured in kilograms with a mass balance (an old-fashioned pair of balancing scales).

The *Very Important Formula* Relating *Mass, Weight* and *Gravity*

weight = mass × gravitational field strength

$$W = m \times g$$

1) Remember, weight and mass are not the same. Mass is in kilograms (kg), weight is in newtons (N).
2) The letter "*g*" represents the strength of the gravity and its value is different for different planets. On Earth $g \approx 10$ N/kg. On the Moon, where the gravity is weaker, *g* is only about 1.6 N/kg.
3) This formula is hideously easy to use:

Example: What is the weight, in newtons, of a 5 kg mass, both on Earth and on the Moon?

Use the formula $W = m \times g$.

On Earth: $W = 5 \times 10 = \underline{50\text{ N}}$ (The weight of the 5 kg mass is 50 N.)

On the Moon: $W = 5 \times 1.6 = \underline{8\text{ N}}$ (The weight of the 5 kg mass is 8 N.)

See what I mean. Hideously easy — as long as you've learnt what all the letters mean.

Learn about gravity now — no point in "weighting" around...

Remember that weight is a force due to gravity and that it changes depending on the strength of the gravitational field the object is in. Gravity can cause circular motion in things like moons and satellites — see page 74.

Q1 Calculate the weight in newtons of a 32 kg mass:
a) on Earth ($g \approx 10$ N/kg)
b) on the Moon ($g \approx 1.6$ N/kg) [2 marks]

Forces and Friction

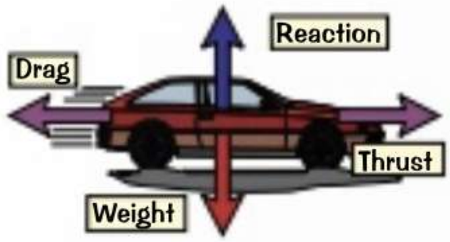
Forces are your friends — without them, you'd never get anywhere, and movement would be impossible.

There are Loads of Different Types of Force

A force is simply a push or a pull. There are lots of different types of force you need to know about:

- GRAVITY or WEIGHT (see previous page) — close to a planet this acts straight downwards.
- REACTION FORCE — acts perpendicular to a surface and away from it (so if the surface is horizontal, the reaction force acts straight upwards.)
- ELECTROSTATIC FORCE between two charged objects. The direction depends on the type of the charge (like charges repel, opposite charges attract) — see page 23.
- THRUST — e.g. PUSH or PULL due to an engine or rocket speeding something up.
- DRAG or AIR RESISTANCE or FRICTION which is slowing the thing down.
- LIFT — e.g. due to an aeroplane wing.
- TENSION in a rope or cable.

You Can Draw the Forces Acting on a Body



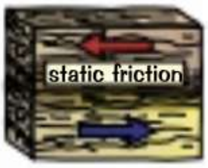
1) Chances are, there are loads of forces acting on you right now that you don't even know about. You don't notice them because they all balance out.
2) Any object with a weight feels a reaction force back from the surface it's on. Otherwise it would just keep falling.
3) When an object moves in a fluid (air, water etc.) it feels drag in the opposite direction to its motion.

Friction is Always There to Slow things Down

1) If an object has no force propelling it along, it will always slow down and stop because of friction (unless you're out in space where there's no friction). Friction is a force that opposes motion.
2) To travel at a steady speed, things always need a driving force to counteract the friction.
3) Friction occurs in three main ways:

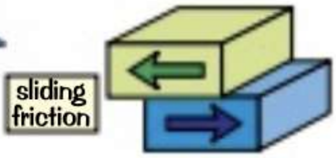
a) Friction Between Solid Surfaces Which Are Gripping

(static friction)



b) Friction Between Solid Surfaces Which Are Sliding Past Each Other

You can reduce both these types of friction by putting a lubricant like oil or grease between the surfaces. Friction between solids can often cause wear of the two surfaces in contact.



c) Resistance or "drag" from fluids (liquids or gases, e.g. air)

The most important factor by far in reducing drag in fluids is keeping the shape of the object streamlined, like sports cars or boat hulls. Lorries and caravans have "deflectors" on them to make them more streamlined and reduce drag.

Roof boxes on cars spoil their streamlined shape and so slow them down. For a given thrust, the higher the drag, the lower the top speed of the car.

The opposite extreme to a sports car is a parachute which is about as high drag as you can get — which is, of course, the whole idea.

In a fluid, FRICTION ALWAYS INCREASES AS THE SPEED INCREASES — see page 9.

This stuff can be a little hard to swallow — you might have to force it down...

We owe a lot to forces really, quietly making the world go round.

Q1 A book is at rest on a table. Draw a diagram showing all the forces acting upon it. [1 mark]

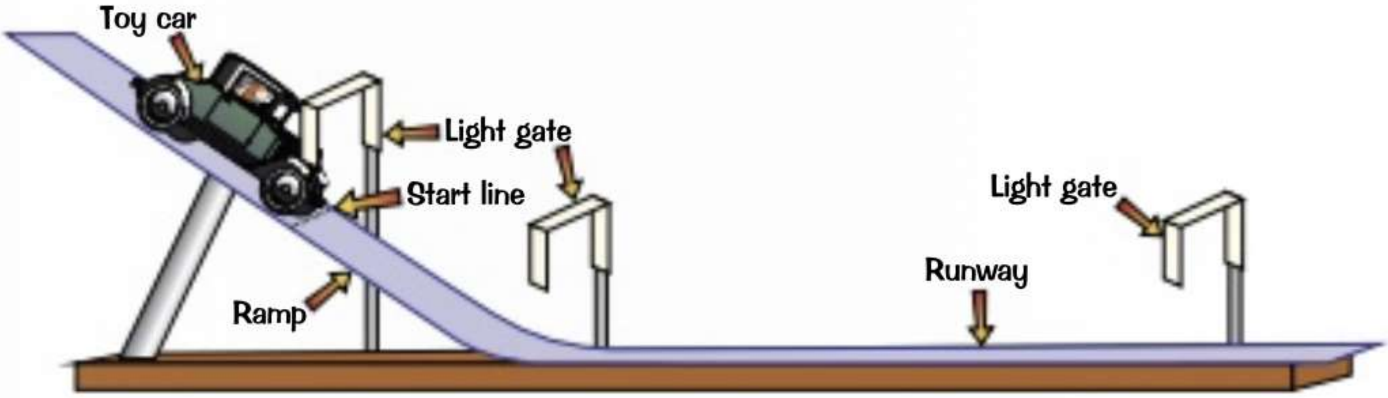
Investigating Motion

PRACTICAL

There's no use in knowing about speed, velocity and acceleration if you don't know how they can be used to describe an object's motion. Here's a simple toy car experiment you can try out yourself.

You can Investigate the Motion of a Toy Car on a Ramp

1) Set up your apparatus like in the diagram below, holding the car still just before the first light gate.



2) Mark a line on the ramp — this is to make sure the car starts from the same point each time.
3) Measure the distance between each light gate — you'll need this to find the car's average speed.
4) Let go of the car just before the light gate so that it starts to roll down the slope.
5) The light gates should be connected to a computer. When the car passes through each light gate, a beam of light is broken and a time is recorded by data-logging software.
6) Repeat this experiment several times and get an average time it takes for the car to reach each light gate.
7) Using these times and the distances between light gates you can find the average speed of the car on the ramp and the average speed of the car on the runway — just divide the distance between the light gates by the average time taken for the car to travel between gates (page 1).

Using light gates means you don't get any timing errors as a result of a person reacting slowly. If you don't have light gates, you could use a stopwatch with a lap function.

You Could Play Around with the Experimental Set-up

You could change different things in this experiment to investigate other factors that might affect the car's motion. Just make sure that if you do change something, every other part of the experiment stays the same.

1) You could try seeing if the mass of the car affects its average speed — just load weights onto it (but make sure you don't overload it so that the wheel axles grind).
2) To see how friction affects the motion of the car you could try placing different materials on the ramp. If you do this, make sure they're laid flat and they don't change the angle of the ramp in any way.
3) You could investigate the acceleration of the car due to gravity by starting it off higher up the ramp and seeing how this affects its average speed between the gates.
4) You could change the angle of the ramp to see how that affects the car's speed down the slope.
5) You could even try it with different cars — see how the size, shape and weight of the car affects how fast it goes down the ramp.

You'd expect the more streamlined ones to go quicker — see page 4.

If you want to investigate motion you'll need to invest in gates...

Make sure you know multiple methods for measuring the speed of an object.

Q1 Why is it better to use a light gate instead of a stopwatch to measure short time intervals? [1 mark]

The Three Laws of Motion

Around about the time of the Great Plague in the 1660s, a chap called Isaac Newton worked out the Three Laws of Motion. At first they might seem kind of obscure or irrelevant, but to be perfectly blunt, if you can't understand these three simple laws then you'll never understand forces and motion:

First Law — Balanced Forces Mean No Change in Velocity

So long as the forces on an object are all balanced, then it'll just stay still, or else if it's already moving it'll just carry on at the same velocity — so long as the forces are all balanced.

1) When a train or car or bus or anything else is moving at a constant velocity then the forces on it must all be balanced.
2) Never let yourself entertain the ridiculous idea that things need a constant overall force to keep them moving — NO NO NO NO NO NO!
3) To keep going at a steady speed, there must be zero resultant force — and don't you forget it.

Second Law — A Resultant Force Means Acceleration

If there is an unbalanced force, then the object will accelerate in that direction.

1) The overall unbalanced force is often called the resultant force (see page 7).
2) An unbalanced (or resultant) force will always produce acceleration (or deceleration).
3) This "acceleration" can take five different forms:
   - Starting
   - stopping
   - speeding up
   - slowing down
   - changing direction.
4) On a force diagram, the arrows will be unequal:

- Don't ever say: "If something's moving there must be an overall resultant force acting on it".
- Not so. If there's an overall force it will always accelerate.
- You get steady speed from balanced forces.
  I wonder how many times I need to say that same thing before you remember it?

Resultant Force = Mass × Acceleration

The three points below are probably pretty obvious:

1) The bigger the force, the greater the acceleration or deceleration.
2) The bigger the mass, the smaller the acceleration.
3) To get a big mass to accelerate as fast as a small mass it needs a bigger force. Just think about pushing heavy trolleys and it should all make sense.

In a nutshell, any resultant force will produce acceleration, and this is the formula for it:

Force = mass × acceleration

$$F = ma$$

m = mass
a = acceleration
F is always the resultant force

The fun's not over — there's one more law of motion still to come...

You've only seen two laws of motion on this page, so the fun continues on the next page. But try this question first...

Q1 A boat is travelling at a constant velocity. What is the resultant force acting on the boat? [1 mark]

The Three Laws of Motion

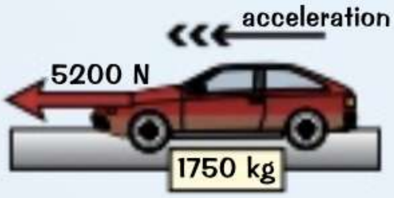
You can use Newton's second law to find an object's acceleration. All you need to know is the object's mass and the resultant force acting on it. You might have to rearrange the equation first though...

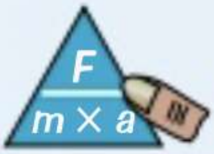
Resultant Force is Real Important — Especially for "F = ma"

1) The notion of resultant force is a really important one for you to get your head round. It's not especially tricky — it's just that it seems to get kind of ignored.
2) In most real situations there are at least two forces acting on an object along any direction. The overall effect of these forces will decide the motion of the object — whether it will accelerate, decelerate or stay at a steady speed.
3) If the forces act along the same line, the "overall effect" is found by just adding or subtracting them (see next page). The overall force you get is called the resultant force. When you use the formula "$F = ma$", F must always be the resultant force.

Example: A car of mass of 1750 kg has an engine which provides a resultant driving force of 5200 N. Find the car's acceleration.

- First draw a force diagram for the car — this will make the situation easier to understand:
- Apply "$F = ma$" using the formula triangle:





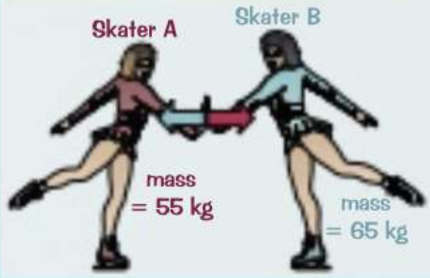
$$a = F/m$$
$$= 5200 \div 1750$$
$$= \underline{3.0\ \text{m/s}^2}$$

The Third Law — Reaction Forces

If object A exerts a force on object B then object B exerts an equal and opposite force on object A.

This is Newton's third law of motion.

1) That means if you push something, say a shopping trolley, the trolley will push back against you, just as hard.
2) And as soon as you stop pushing, so does the trolley. Kinda clever really.
3) So far so good. The slightly tricky thing to get your head round is this — if the forces are always equal, how does anything ever go anywhere? The important thing to remember is that the two forces are acting on different objects. Think about a pair of ice skaters:



- When skater A pushes on skater B (the 'action' force), she feels an equal and opposite force from skater B's hand (the 'reaction' force).
- Both skaters feel the same sized force, in opposite directions, and so accelerate away from each other.
- Skater A will be accelerated more than skater B, though, because she has a smaller mass — remember $F = ma$.

4) It's the same sort of thing when you go swimming. You push back against the water with your arms and legs, and the water pushes you forwards with an equal-sized force in the opposite direction.

I have a reaction to forces — they bring me out in a rash...

Newton's 3rd law really trips people up, so make sure you understand exactly what objects the forces are acting on and how that results in movement (or lack of it). Then have a crack at this question to practise what you know.

Q1 A full shopping trolley and an empty one are moving at the same speed. Explain why it is easier to stop the empty trolley than the full trolley over the same amount of time. [1 mark]

Combining Forces

When you're talking about the forces acting on an object, it's not enough to just talk about the size of each force. You need to know their direction too so you know which way the object will accelerate.

Vectors Have Size and Direction — Scalar Quantities Only Have Size

1) When there are multiple forces acting on an object, it's often useful to know the resultant force acting on the object (see page 7). To do this you need to know the size of all the different forces acting on the object and their direction.
2) Force is a vector quantity — vector quantities have a size and a direction.
3) Lots of physical quantities are vector quantities:

   Vector quantities: force, velocity, acceleration, momentum, etc.

Vector quantities are usually represented by arrows.

4) Some physical quantities only have size and no direction. These are called scalar quantities:

   Scalar quantities: mass, temperature, time, length, etc.

To Work Out Resultant Force You Need To Combine Vectors

Example: What's the resultant force of a 220 N force north, a 180 N force south and a 90 N force south?

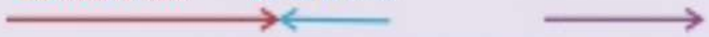
Start by choosing a direction as the positive — let's say north. This means you add any forces in the north direction and subtract any forces in the south direction.

Resultant force = 220 – 180 – 90 = –50 N, so 50 N south.

Example: a) The jets on the plane are producing a thrust of 22 000 N east, and the friction from the air is 8000 N west at this speed. What is the resultant force acting on the plane?

Draw the vectors end to end:

Engine thrust 22 000 N east + Friction 8000 N west = Resultant Force 14 000 N east



b) Find the acceleration of the plane in part a) if it has a mass of 10 000 kg.

Rearrange $F = ma$ (page 6) using the formula triangle to give:

$a = F/m = 14\ 000 \div 10\ 000 = 1.4\ \text{m/s}^2$

What's a vector's favourite band? One Direction...

You use the same trick to combine any vectors — velocity vectors, momentum vectors, acceleration vectors, and so on (but don't mix different kinds of vectors — you can't add a velocity vector to an acceleration, for example). Just draw the vectors end to end and, with a bit of simple maths, you can find the overall (resultant) vector.

Q1 A 2 kg mass is on the end of a stretched spring. Its weight is a force of approximately 20 N and acts vertically downwards. The spring exerts a force on the mass of 24 N directed vertically upwards.

a) Find the resultant force acting on the mass. [1 mark]

b) Calculate the acceleration of the mass. [2 marks]

Terminal Velocity

Okay... so we all know that gravity is responsible for accelerating skydivers towards the ground when they jump out of a plane. But have you ever wondered why they don't keep on accelerating and go faster and faster and faster... maybe not... but you're about to find out anyway.

Moving Objects Can Reach a *Terminal Velocity*

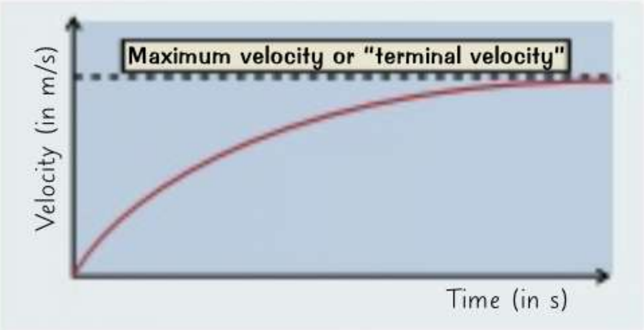
This whole terminal velocity thing is explained by Newton's laws of motion (see page 6).

Frictional forces increase with speed — but only up to a certain point.

1) When an object first starts to fall, it has much more force accelerating it than resistance slowing it down.
2) As its velocity increases, the resistance builds up.

It's a bit like when you (very carefully) put your hand out of the window of a car as it moves along. At low speeds, you hardly notice the air pushing against your hand. But as the car goes faster, the air pushes your hand backwards much harder.

3) This resistance force gradually reduces the acceleration until eventually the resistance force is equal to the accelerating force. At this point, the object won't be able to accelerate any more. It will have reached its maximum velocity or terminal velocity.



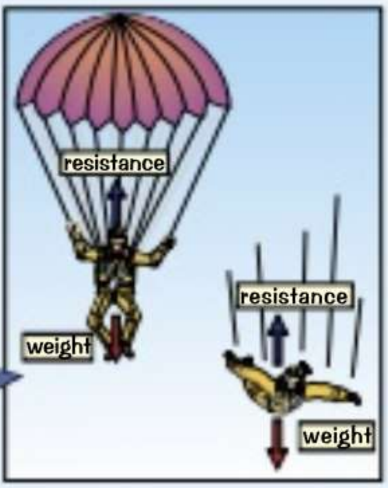
The *Terminal Velocity* of *Falling Objects* Depends on Their *Shape and Area*

1) The accelerating force acting on all falling objects is gravity and it would make them all accelerate at the same rate, if it wasn't for air resistance.
2) To prove this, on the Moon, where there's no air, hamsters and feathers dropped simultaneously will hit the ground together.
3) However, on Earth, air resistance causes things to fall at different speeds, and the terminal velocity of any object is determined by its drag compared to its weight. The drag depends on its shape and area.

The most important example is the human skydiver.

1) Without his parachute open he has quite a small area and a force equal to his weight pulling him down.
2) He reaches a terminal velocity of about 120 mph.
3) But with the parachute open, there's much more air resistance (at any given speed) and still only the same force pulling him down.
4) This means his terminal velocity comes right down to about 15 mph, which is a safe speed to hit the ground at.

- In both cases, once the skydiver has reached terminal velocity, resistance = weight.
- The difference is the speed at which that happens.



My terminal velocity is very slow — I always get distracted by airport shops...

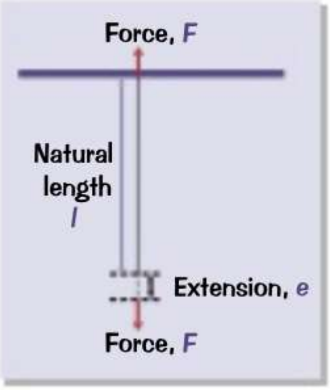
Just remember — the terminal velocity of an object is related to its weight and drag. Objects with a smaller weight and larger surface area have a smaller terminal velocity and so take longer to fall long distances.

Q1	Explain why an object falling through the air will eventually stop accelerating.	[2 marks]
Q2	Explain why a skydiver falls more slowly after they've opened their parachute.	[2 marks]

Hooke's Law

Applying a force to an object can cause it to change shape temporarily... or even permanently.

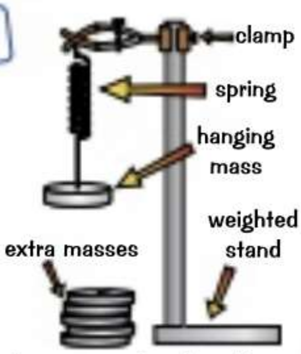
Hooke's Law Says that Extension is Proportional to Force



1) The length of an unstretched metal wire is called its natural length, *l*.
2) If a metal wire (see right) is supported at the top and then a weight attached to the bottom, it stretches. The weight pulls down with force *F*, producing an equal and opposite force at the support.
3) This will also happen to helical springs and any object that will stretch without immediately snapping or deforming.
4) Robert Hooke discovered in 1676 that the extension of a stretched wire is proportional to the load, or force. This relationship is now called Hooke's law.
5) A metal spring (or other object) will also obey Hooke's law if a pair of opposite forces are applied to each end.

You Can Investigate Hooke's Law with a Spring

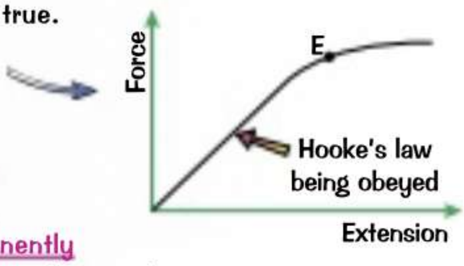
PRACTICAL



1) Set up the apparatus as shown to the right. Make sure you have plenty of extra masses, and measure the weight of each (with a balance).
2) Measure the length of the spring (e.g. with an accurate mm ruler) when no load is applied. Ensure the ruler is vertical (e.g. with a set square) and measure the spring at eye level. (This is the spring's natural length.)
3) Add one mass at a time and allow the spring to come to rest, then measure the new length of the spring. The extension is the change in length from the original length. Adding a marker to the top and bottom of the spring might make measuring lengths easier. Repeat this process until you have enough measurements (no fewer than 6).
4) Once you're done, repeat the experiment and calculate an average value for the length of the spring for each applied weight.
5) Plot your results on a graph — show force (i.e. the total weight) on the vertical axis and the total extension on the horizontal axis. You should find that the same increase in the weight on the end of the spring always leads to the same increase in extension — this is Hooke's law in action.
6) Repeat the experiment using a metal wire or a rubber band instead of the spring.

Hooke's law Stops Working when the Force is Great Enough

1) There's a limit to the force you can apply for Hooke's law to stay true. The graph shows force against extension for a typical metal wire.
2) The first part of the graph shows Hooke's law being obeyed — there's a straight-line relationship between force and extension.
3) When the force becomes great enough, the graph starts to curve.
4) The point marked E on the graph is called the elastic limit. If you increase the force past the elastic limit, the material will be permanently stretched. When all the force is removed, the material will be longer than at the start.
5) Some materials, like rubber, only obey Hooke's law for really small extensions.



A Material Can Return to its Original Shape After an Elastic Deformation

1) If a material returns to its original shape once the forces are removed, it displays elastic behaviour.
2) Metals display elastic behaviour as long as Hooke's law is obeyed.

Sod's law — if you don't learn it, it'll be in the exam...

Okay, so this isn't the most riveting stuff in the world — but at least it's fairly simple.

Q1 What does a force-extension graph demonstrating Hooke's law look like? [2 marks]

Stopping Distances

Looking at things simply — if you need to stop in a given distance... then the faster you're going, the bigger braking force you'll need. But in real life there are loads of other factors too...

Many Factors Affect Your Total Stopping Distance

1) The stopping distance of a car is the distance covered in the time between the driver first spotting a hazard and the car coming to a complete stop. They're pretty keen on this for exam questions, so make sure you learn it properly.
2) The distance it takes to stop a car is divided into the thinking distance and the braking distance.

Stopping Distance = Thinking Distance + Braking Distance

1) Thinking Distance

"The distance the car travels in the time between the driver noticing the hazard and applying the brakes."

It's affected by two main factors:

a) **How fast you're going** — obviously. Whatever your reaction time, the faster you're going, the further you'll go.

b) **Your reaction time** — This is affected by things like tiredness, drugs, alcohol and old age. Inexperience can also affect your reaction time.

2) Braking Distance

"The distance the car travels during its deceleration whilst the brakes are being applied."

It's affected by four main factors:

a) **How fast you're going** — The faster you're going the further it takes to stop.

b) **The mass of the vehicle** — with the same brakes, the larger the mass of a vehicle, the longer it takes to stop. A car won't stop as quickly when it's full of people and luggage and towing a caravan.

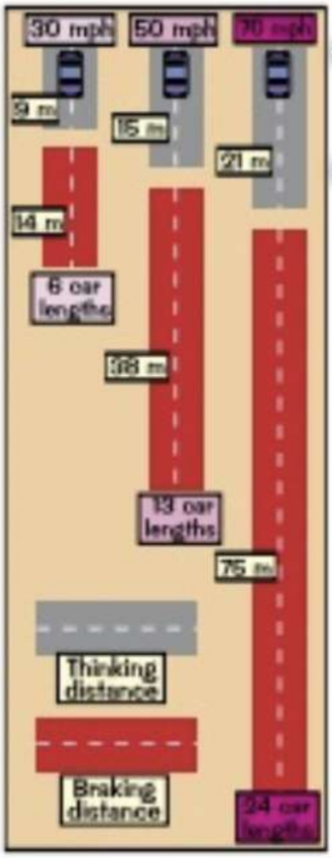
c) **How good your brakes are** — all brakes must be checked and maintained regularly. Worn or faulty brakes will let you down catastrophically just when you need them the most, i.e. in an emergency.

d) **How good the grip is** — this depends on three things:
1) road surface,
2) weather conditions,
3) tyres.

To avoid an accident, drivers need to leave enough space between their car and the one in front so that if they have to stop suddenly they can do so safely. 'Enough space' means the stopping distance for whatever speed they're going at. Speed limits are important because speed affects stopping distance so much.

Bad visibility can also be a major factor in accidents — lashing rain, thick fog, bright oncoming lights, etc. might mean that a driver doesn't notice a hazard until they're quite close to it — so they have a much shorter distance available to stop in.

The figures below for typical stopping distances are from the Highway Code. It's frightening to see just how far it takes to stop when you're going at 70 mph.



Stop right there — and learn this page...

Leaves, diesel spills and muck on t'road are serious hazards because they're unexpected. Wet or icy roads are always much more slippy than dry roads, but often you only discover this when you try to brake.

Q1 Explain two factors that affect how quickly a vehicle can stop after the driver has noticed a hazard. [4 marks]

Momentum and Collisions

A large rugby player running very fast will be harder to stop than a scrawny one jogging — that's momentum.

Momentum = Mass × Velocity

p is the symbol for momentum.

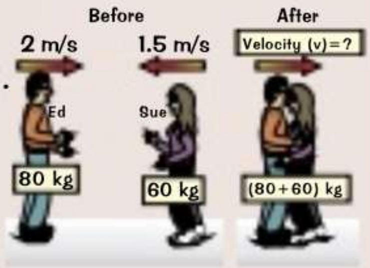
1) The greater the mass of an object and the greater its velocity, the more momentum the object has.
2) Momentum is a vector quantity (page 8) — it has size and direction (like velocity, but not speed).

Momentum (kg m/s) = Mass (kg) × Velocity (m/s)

Momentum Before = Momentum After

Momentum is conserved when no external forces act — total momentum after is the same as it was before.

Two skaters approach each other, collide and move off together as shown. At what velocity do they move after the collision?



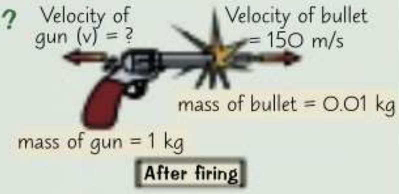
1) Choose which direction is positive — I'll say 'positive' means 'to the right'.
2) Total momentum before collision = Ed's momentum + Sue's momentum
$= \{80 \times 2\} + \{60 \times (-1.5)\}$
$= 70$ kg m/s
3) Total momentum after collision = momentum of Ed and Sue together
$= 140 \times v$
4) So $140v = 70$, i.e. $v = 0.5$ m/s to the right

Forces Cause Changes in Momentum

1) When a force acts on an object, it causes a change in momentum.

$$\text{force (N)} = \frac{\text{change in momentum (kg m/s)}}{\text{time (s)}} \quad \text{or} \quad F = \frac{(mv - mu)}{t}$$

A gun fires a bullet as shown. At what speed does the gun move backwards?



1) Choose which direction is positive — I'll use 'to the right' as 'positive'.
2) Total momentum before firing = 0 kg m/s
3) Total momentum after firing = bullet's momentum + gun's momentum
$= (0.01 \times 150) + (1 \times v)$
$= 1.5 + v$
4) So $1.5 + v = 0$, i.e. $v = -1.5$ m/s. So the gun moves backwards at 1.5 m/s.

This is the gun's recoil.

Find the force exerted on the gun if it is accelerated for 0.1 seconds.

1) Momentum of gun before firing $= mu = 1 \times 0 = 0$ kg m/s
2) Momentum of gun after firing $= mv = 1 \times -1.5 = -1.5$ kg m/s
3) Force $= \frac{mv - mu}{t} = \frac{-1.5 - 0}{0.1} = -15$ N

By Newton's Third Law, this means the force on the bullet must be 15 N in the opposite direction.

2) A larger force means a faster change of momentum (and so a greater acceleration — see page 6).
3) Likewise, if someone's momentum changes very quickly (like in a car crash), the forces on the body will be very large, and more likely to cause injury.
4) This is why cars are designed to slow people down over a longer time when they crash — the longer it takes for a change in momentum, the smaller the force (and the less severe the injuries are likely to be).

CRUMPLE ZONES crumple on impact, increasing the time taken for the car to stop.

SEAT BELTS stretch slightly, increasing the time taken for the wearer to stop. This reduces the forces acting on the chest.

AIR BAGS also slow you down more gradually.

Learn this stuff — it'll only take a moment... um...

Momentum is a pretty fundamental bit of physics — learn it well. Then have a go at this question.

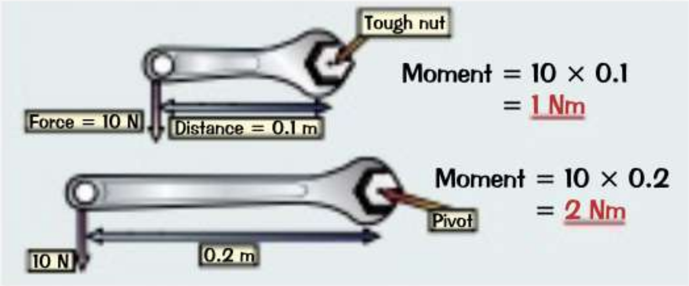
Q1 Calculate the force needed to accelerate a 58 g tennis ball from rest to 34 m/s in 11.6 ms. [3 marks]

Turning Effects and Centre of Gravity

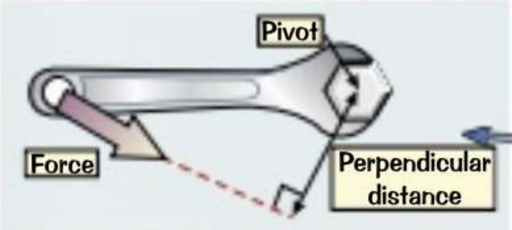
Forces that cause turning effects — e.g. from good ol' spanners and levers. Not very difficult... not very exciting either. Expect to be royally sick of pivots and centre of gravity by the time you've finished these pages.

A Moment is the Turning Effect of a Force

MOMENT (Nm) = FORCE (N) × perpendicular DISTANCE (m) between line of action and pivot



1) The force on the spanner causes a turning effect or moment on the nut. A larger force would mean a larger moment.
2) Using a longer spanner, the same force can exert a larger moment because the distance from the pivot is greater.

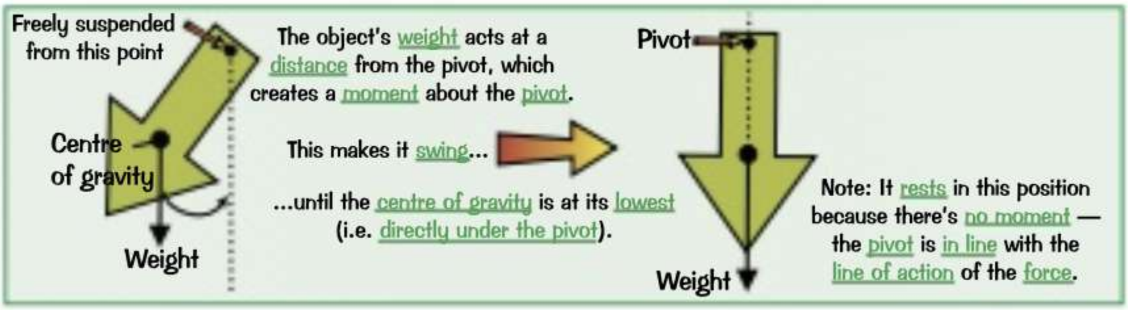


3) To get the maximum moment (or turning effect) you need to push at right angles (perpendicular) to the spanner.
4) Pushing at any other angle means a smaller moment because the perpendicular distance between the line of action and the pivot is smaller.

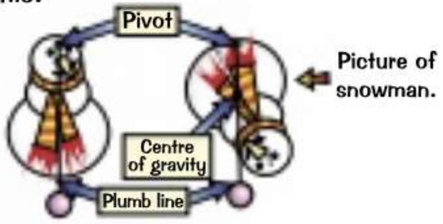
The Centre of Gravity Hangs Directly Below the Point of Suspension

Paper 2

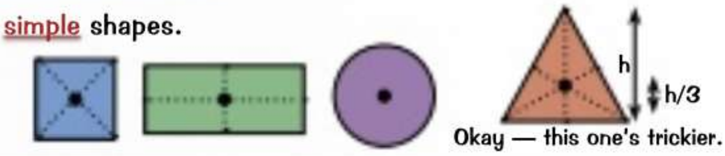
1) You can think of the centre of gravity of an object as the point through which the weight of a body acts.
2) A freely suspended object will swing until its centre of gravity is vertically below the point of suspension.



3) This means you can find the centre of gravity of any flat shape like this:
   1) Suspend the shape and a plumb line from the same point, and wait until they stop moving.
   2) Draw a line along the plumb line.
   3) Do the same thing again, but suspend the shape from a different pivot point.
   4) The centre of gravity is where your two lines cross.



4) But you don't need to go to all that trouble for simple shapes. You can quickly guess where the centre of gravity is by looking for lines of symmetry.



Okay — this one's trickier.

Take a moment to find your centre...

Think of the extra force you need to open a door by pushing it near the hinge compared to at the handle — the distance from pivot is less, so you need more force to get the same moment. Best way to understand it is to get loads of practice.

P2 Q1 A 10 N force is applied at right angles to a door, 85 cm from its hinges. Find the moment created. [1 mark] P2

Principle of Moments

Once you can calculate moments, you can work out if a seesaw is balanced. Useful thing, Physics.

A Question of Balance — Are the Moments Equal?

The principle of moments says:

If an object is balanced then:
Total Anticlockwise Moments = Total Clockwise Moments

You can use this idea to help solve problems where forces are acting on a balanced object.

Example: Your younger brother weighs 300 N and sits 2 m from the pivot of a seesaw. If you weigh 700 N, where should you sit to balance the seesaw?

For the seesaw to balance: Total anticlockwise moments = total clockwise moments

anticlockwise moment = clockwise moment
$300 \times 2 = 700 \times y$
$y = \underline{0.86\text{ m}}$

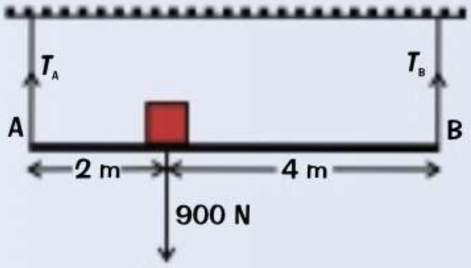
Ignore the weight of the seesaw — its centre of mass is on the pivot, so it doesn't have a turning effect.

Forces are Not Always Equal Across All Supports

"Light" means you can ignore the weight in your calculations. In general, if they don't tell you the weight, you can ignore it.

1) If a light rod is being supported at both ends, the upwards force provided by each support won't always be the same.
2) If a heavy object is placed on the rod, the support closest to the object will provide a larger force.

Example: A 6 m long light rod is suspended by two cables (A and B) at its ends. A 900 N weight is placed 4 m from one end, as shown below. Work out the tension in cable A, T_A, and the tension in cable B, T_B.



The weight is balanced by the tension forces in the cables. To work out the forces, start at one end and treat that end as a pivot, so you can work out the upward force at the other end:

clockwise moment around B = anticlockwise moment around B
$T_A \times 6 = 900 \times 4$

So $T_A = 3600/6 = \underline{600\text{ N}}$

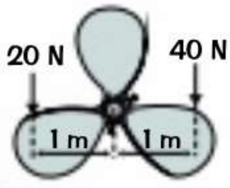
Then you can work out the force in B as we know the vertical forces balance:

$900\text{ N} = T_A + T_B$
So $T_B = 900 - T_A = 900 - 600 = \underline{300\text{ N}}$

And if the Moments are Not Equal...

If the Total Anticlockwise Moments do not equal the Total Clockwise Moments, there will be a Resultant Moment

...so the object will turn.



clockwise moments = 40 × 1 = 40 Nm
anticlockwise moments = 20 × 1 = 20 Nm
so the propellor will turn clockwise.

Balanced moments — nope, not had one of those for a while...

Any time you've got equal clockwise and anticlockwise moments, you've got equilibrium, and your thing-on-a-pivot will stay still. Remember that and you won't go far wrong (as long as you calculate moments properly).

P2 Q1 How far from the pivot should a 27 N anticlockwise force be applied to balance a 108 Nm clockwise moment? [2 marks] P2

Revision Questions for Section 1

Well, that nearly wraps up forces and motion... but you're not quite done yet.

- Try these questions and tick off each one when you get it right.
- When you've done all the questions for a topic and are completely happy with it, tick off the topic.

Speed, Distance and Time (p.1-2) ☐

1) What's the relationship between the average speed, distance moved and time for a moving object? ☐
2) How long would a robot take to reach 2.7 m/s from rest if it had an acceleration of 0.5 m/s^2? ☐
3) What does a straight, horizontal line show on a distance-time graph? ☐
4) What does a straight, horizontal line show on a velocity-time graph? ☐
5) How can you find the acceleration of an object from its velocity-time graph? ☐
6) How could you find the distance travelled by an object from its velocity-time graph? ☐

Forces and Newton's Laws of Motion (p.3-9) ☐

7) What's the force that acts between all masses called? ☐
8) What's the difference between mass and weight? ☐
9) The value of g on the moon is 1.6 N/kg. How much would a mass of 60 kg weigh on the Moon? ☐
10) In what direction does friction always act, and how does friction change with the speed of an object? ☐
11) Describe a simple experiment you could carry out to investigate the motion of a toy car. ☐
12) What will happen to the velocity of a moving object if there is an unbalanced force on it? ☐
13) What's the relationship between force, mass and acceleration? ☐
14) A 25 kg rock is hurled with a force of 25 000 N. What will its acceleration be? ☐
15) What is Newton's third law of motion? ☐
16) What's the difference between a vector quantity and a scalar quantity? Which of these is force? ☐
17) What's the resultant force on a train with a driving force of 19 000 N and a drag of 13 500 N? ☐
18) Why does a falling object reach a terminal velocity? ☐

Hooke's Law, Stopping Distances and Momentum (p.10-12) ☐

19) Describe a simple experiment you could use to investigate Hooke's law using a metal wire. ☐
20) What does elastic behaviour mean? ☐
21) State two factors that could affect how far a vehicle travels between the driver noticing a hazard and starting to brake. ☐
22) What's the relationship between momentum, mass and velocity? ☐
23) What's the mass of a car that has a momentum of 14 700 kg m/s when moving at 15 m/s? ☐
24) A 2.5 kg kitten hurtles into a stationary 3.7 kg puppy at 5 m/s and sticks. Find their speed after the collision. ☐
25) A car's brakes apply a force of 230 N for 10 seconds. Find its change in momentum. ☐
26) How do crumple zones in cars reduce the risk of injury to the passengers in a crash? ☐

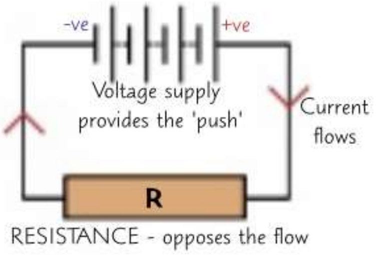
Turning Forces and Moments (p.13-14) ☐

27) Find the moment produced by a 5 N force acting at a perpendicular distance of 1.3 m from a pivot. ☐
28) What name is given to the point through which all of an object's weight acts? ☐
29) A light rod is supported by two bricks, one at each end of the rod. Which brick feels more force when a mass is placed on one end? ☐

Circuits — The Basics

Electricity's great. But not if the words don't mean anything to you. Hey, I know — learn them now!

The Properties of a Circuit

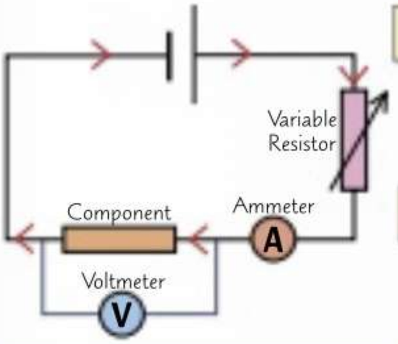


1) Current is the rate of flow of charge round the circuit. Electrons usually carry the charge — they're negatively charged particles. Current will only flow through a component if there is a voltage across that component. Unit: ampere (amp for short), A.
2) Voltage is what drives the current round the circuit. Kind of like "electrical pressure". You may also see it called potential difference (or p.d.). Unit: volt, V.
3) Resistance is anything in the circuit which slows the flow down. If you add more components to the circuit (one after the other) there will be a higher overall resistance. Unit: ohm, Ω.
4) There's a balance. The voltage is trying to push the current round the circuit, and the resistance is opposing it — the relative sizes of the voltage and resistance decide how big the current will be:

If you increase the voltage — then more current will flow.
If you increase the resistance — then less current will flow
(or more voltage will be needed to keep the same current flowing).

The Standard Test Circuit

This is without doubt the most totally bog-standard circuit the world has ever known. So know it.



The Ammeter

1) Measures the current (in amps) flowing through the component.
2) Must be placed in series (see page 19) anywhere in the main circuit, but never in parallel like the voltmeter.

The Voltmeter

1) Measures the voltage (in volts) across the component.
2) Must be placed in parallel (see page 19) around the component under test — NOT around the variable resistor or the battery!

Five Important Points

1) This very basic circuit is used for testing components, and for getting I-V graphs for them.
2) The component, the ammeter and the variable resistor are all in series, which means they can be put in any order in the main circuit. The voltmeter, on the other hand, can only be placed in parallel around the component under test, as shown. Anywhere else is a definite no-no.
3) As you vary the variable resistor it alters the current flowing through the circuit.
4) This allows you to take several pairs of readings from the ammeter and voltmeter.
5) You can then plot these values for current and voltage on a I-V graph (see next page).

Mains Supply is a.c., Battery Supply is d.c.

1) The UK mains electricity supply is approximately 230 volts.
2) It is an a.c. supply (alternating current), which means the current is constantly changing direction.
3) By contrast, cells and batteries supply direct current (d.c.). This just means that the current keeps flowing in the same direction.

The standard test circuit — it's like an obstacle course for electricity...

Electrons in circuits actually move from –ve to +ve, but it's conventional to draw current as though it's flowing from +ve to –ve. It's what early physicists thought (before they found out about the electrons), and it's stuck.

Q1 Draw the standard test circuit. [2 marks]

Resistance and $V = I \times R$

The voltage across and current through a component are linked by resistance — if you plot them against each other, you can see how the resistance changes.

There's a Formula Linking V and I

You need to know this formula and be able to use and rearrange it:

Voltage = Current × Resistance

Example: A 4 Ω resistor in a circuit has a voltage of 6 V across it. What is the current through the resistor?

Use the formula $V = I \times R$. We need to find I, so the version we need is $I = V/R$.

So $I = 6/4 =$ 1.5 A

You can use this formula to work out the resistance for a pair of values (V, I) from an I-V graph, by sticking them in the formula $R = V/I$.

The gradient (slope) of an I-V graph shows you how the resistance of the component behaves. The steeper the graph the lower the resistance.

A straight-line graph has a constant gradient and shows a constant resistance. If the graph curves, it means the resistance is changing.

Four Hideously Important Current-Voltage Graphs

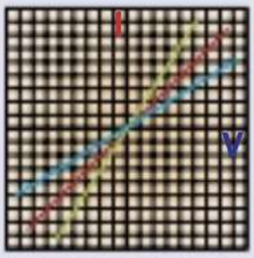
Current-voltage (I-V) graphs show how the current varies as you change the voltage. Learn these four real well:

Wire

The current through a wire (at constant temperature) is proportional to voltage.

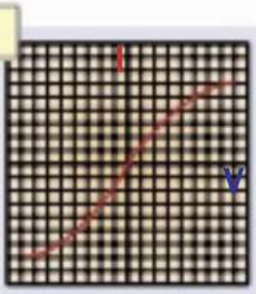
Different Resistors

The current through a resistor (at constant temperature) is proportional to voltage. Different resistors have different resistances, hence the different slopes.



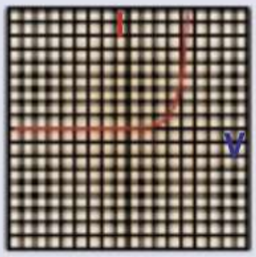
Metal Filament Lamp

As the temperature of the metal filament increases, the resistance increases, hence the curve.



Diode

Current will only flow through a diode in one direction, as shown.



Revise this page — without any resistance...

Make sure you know how current, voltage and resistance are linked. You might need to draw an I-V graph in the exam, or interpret one to find the resistance — make sure you can tell your lamp graphs from your diode graphs.

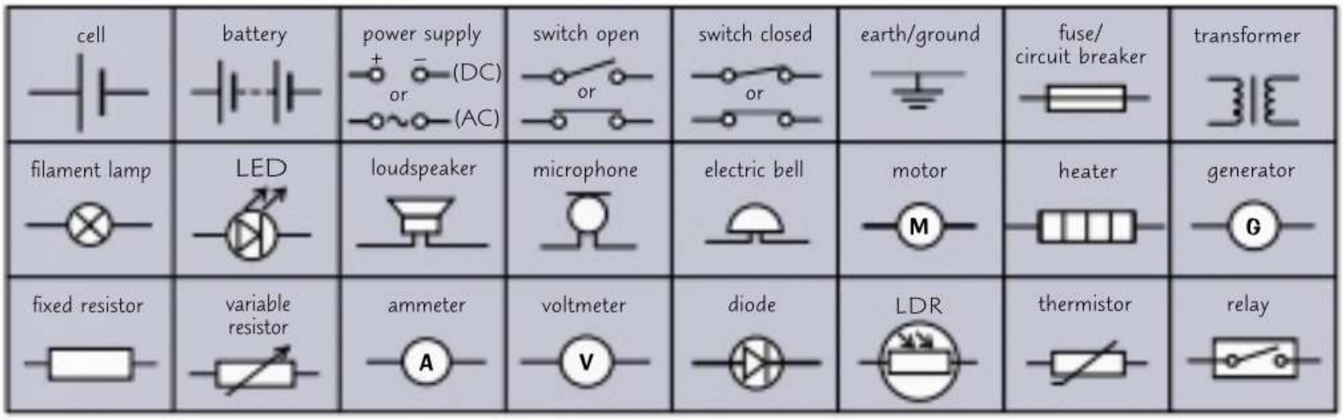
Q1 A 1.5 A current flows through a resistor when it is connected to a 9.0 V battery.
Calculate the resistance of the resistor. [2 marks]

LDRs, Thermistors and LEDs

There are some really useful components that can be used in circuits to make all sorts of appliances work...

Circuit Symbols You Should Know:

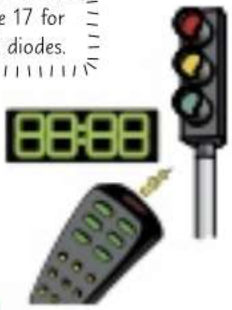
You will need these for the exam — so learn them now.



Light-Emitting Diodes are Really Useful

See page 17 for more on diodes.

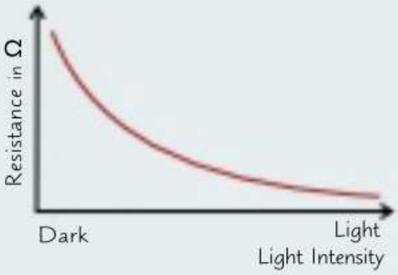
1) Light-emitting diodes (LEDs) emit light when a current flows through them in the forward direction. They have lots of practical applications.
2) They are used for the numbers on digital clocks, in traffic lights and in remote controls.
3) Unlike a light bulb, they don't have a filament that can burn out.

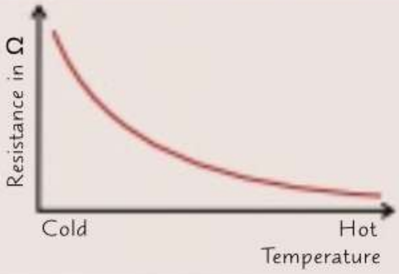


LEDs, like lamps, indicate the presence of current in a circuit.
They are often used in appliances to show that they are switched on.

Some Components Can Change Resistance

1) A light-dependent resistor (LDR) is a special type of resistor that changes its resistance depending on how much light falls on it.
2) In bright light, the resistance falls and in darkness, the resistance is highest.
3) This makes it a useful device for various electronic circuits, e.g. burglar detectors.





1) A thermistor is a temperature-dependent resistor.
2) In hot conditions, the resistance drops and in cool conditions, the resistance goes up.
3) Thermistors make useful temperature detectors, e.g. car engine temperature sensors, thermostats and fire alarms.

I'm a thermistor for ice cream — in heat my resistance drops...

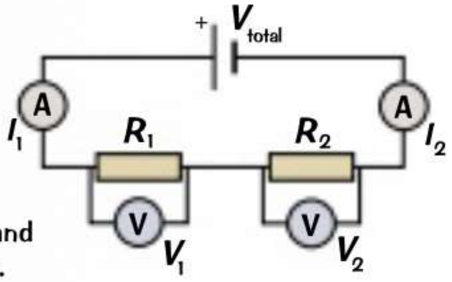
LDRs and thermistors are useful little things. LDRs can be used for automatic light switches and in digital cameras. Thermistors can be used in thermostats and fire alarms.

Q1 A simple circuit consists of an thermistor and a battery connected in a single loop.
Describe how the current in the circuit changes as the temperature of the thermistor increases. [3 marks]

Series and Parallel Circuits

You can connect up circuits in two different ways — in series or in parallel. You need to know the differences between them, and be able to work out what sort of circuit should be used in real-life applications.

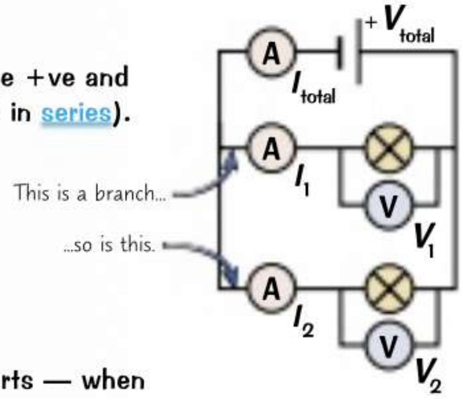
Series Circuits — All or Nothing



1) In series circuits, the different components are connected in a line, end to end, between the +ve and –ve of the power supply (except for voltmeters, which are always connected in parallel, but they don't count as part of the circuit).
2) If you remove or disconnect one component, the circuit is broken and they all stop working. This is generally not very handy, and in practice only a few things are connected in series, e.g. fairy lights.
3) For a series circuit:
   - There's a bigger supply p.d. when more cells are in series (if they're all connected the same way). E.g. when two batteries with a p.d. of 1.5 V are connected in series they supply 3 V between them.
   - The current is the same everywhere. $I_1 = I_2$ etc. The size of the current depends on the total potential difference and the total resistance of the circuit ($I = V_{total} \div R_{total}$).
   - The total potential difference of the supply is shared between components. The p.d. for each component depends on its resistance.
   - The total resistance of the circuit depends on the number of components and the type of components used. The total resistance is the sum of the resistance of each component in the circuit — $R_{total} = R_1 + R_2 + ...$

p.d. = potential difference

Parallel Circuits — Everything is Independent



1) In parallel circuits, each component is separately connected to the +ve and –ve of the supply (except ammeters, which are always connected in series).
2) If you remove or disconnect one component, it will hardly affect the others at all.
3) This is obviously how most things must be connected, for example in cars and in household electrics. Each light switch in your house is part of a branch of a parallel circuit — it just turns one light (or set of lights) on and off.
4) Everyday circuits often contain a mixture of series and parallel parts — when looking at components on the same branch the rules for series circuits apply.
5) For a parallel circuit:
   - The potential difference is the same across all branches. $V_1 = V_2$ etc.
   - Current is shared between branches. The total current flowing around the circuit is equal to the total of all the currents through the separate components. $I_{total} = I_1 + I_2$ etc.
   - In a parallel circuit, there are junctions where the current either splits or rejoins. The total current going into a junction equals the total current leaving it, as charge can't just disappear or appear.
   - The current through a branch depends on the resistance of the branch — the higher the resistance, the harder it is for charge to flow, and so the lower the current in that branch. If two identical components are connected in parallel then the same current will flow through each component.
   - The total resistance of the circuit decreases if you add a second resistor in parallel.

Series circuits — they're no laughing matter...

Get those rules straightened out in your head, then have a go at these questions to test what you can remember.

Q1 Calculate the current in a series circuit containing a 12 V battery, a 7 Ω resistor and an 8 Ω resistor. [3 marks]

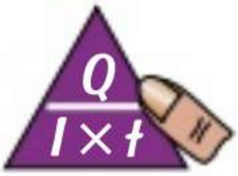
Charge, Voltage and Energy Change

Charge can be positive or negative — and when charge flows it is called current.

Charge Through a Circuit Depends on Current and Time

1) Current is the rate of flow of electrical charge (in amperes, A) around a circuit (see page 16).
2) In solid metal conductors (e.g. copper wire) charge is carried by negatively charged electrons.
3) When current (I) flows past a point in a circuit for a length of time (t) then the charge (Q) that has passed is given by this formula:

Charge = Current × Time



4) More charge passes around a circuit when a bigger current flows.

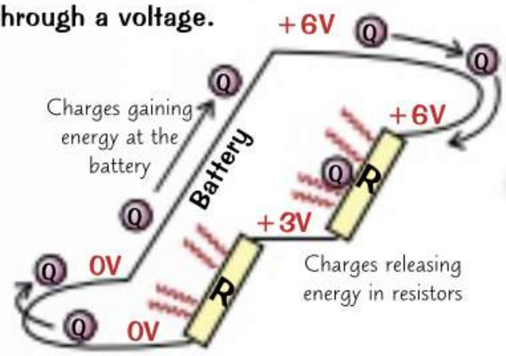
Example: A battery charger passes a current of 2.5 A through a cell over a period of 4 hours.
How much charge does the charger transfer to the cell altogether?
$Q = I \times t = 2.5 \times (4 \times 60 \times 60) = 36\,000$ C (36 kC)

The time needs to be in seconds.

Charge is measured in coulombs, C.

When a Charge Drops Through a Voltage it Transfers Energy

1) When an electrical charge (Q) goes through a change in voltage (V), then energy (E) is transferred.
2) Energy is supplied to the charge at the power source to 'raise' it through a voltage.
3) The charge gives up this energy when it 'falls' through any voltage drop in components elsewhere in the circuit.
4) The bigger the change in voltage, the more energy is transferred for a given amount of charge passing through the circuit.
5) That means that a battery with a bigger voltage will supply more energy to the circuit for every coulomb of charge which flows round it.
6) This is because the charge is raised up 'higher' at the start — and as the diagram shows, more energy will be dissipated in the circuit too.



Voltage is the energy transferred per unit charge passed

7) The unit for voltage, the volt, is defined as:

One volt is one joule per coulomb

8) You can calculate the energy transferred (in joules, J) to or from an amount of charge as it passes through a voltage using the equation:

Energy transferred = Charge × Voltage

9) Combining this with $V = I \times R$ from page 17, you can also calculate the energy transferred by an amount of charge as it passes through a resistance using the equation:

Energy transferred = Charge × Current × Resistance

Pole volting — athletics for electrons...

Make sure you know how voltage and energy transferred are linked — energy is transferred to and from a charge when it passes through a voltage difference. The diagram above is a useful one to remember...

Q1 Calculate the energy transferred to 10 000 C of charge as it passes through a 200 V source. [2 marks]

Electrical Safety

Now then, did you know... electricity is dangerous. It can kill you. Well just watch out for it, that's all.

Appliances must be Earthed or Insulated

1) There are three wires in a plug — live, neutral and earth.
2) Only the live and neutral wires are usually needed, but if something goes wrong, the earth wire stops you getting hurt.
3) The LIVE WIRE alternates between a HIGH +VE AND –VE VOLTAGE of about 230 V.
4) The NEUTRAL WIRE is always at 0 V.
5) Electricity normally flows in through the live wire and the neutral wire.
6) The EARTH WIRE and fuse (or circuit breaker) are just for safety and work together — see below.

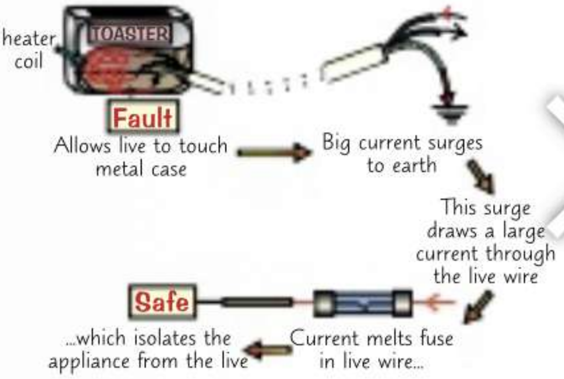
Positive can be written as +ve and negative as –ve.

All appliances with metal cases must be "earthed" to reduce the danger of electric shock. "Earthing" just means the case must be attached to an earth wire. An earthed conductor can never become live.

If the appliance has a plastic casing and no metal parts showing then it's said to be double insulated. The plastic is an insulator, so it stops a current flowing — which means you can't get a shock. Anything with double insulation doesn't need an earth wire — just a live and neutral.

Earthing and Fuses Prevent Fires and Shocks

1) If a fault develops in which the live somehow touches the metal case, then because the case is earthed, a big current flows through the live wire, the case and the earth wire.
2) This surge in current 'blows' (melts) the fuse (or trips the circuit breaker — see below), which cuts off the live supply.
3) This isolates the whole appliance, making it impossible to get an electric shock from the case. It also prevents the risk of fire caused by the heating effect of a large current.



Allows live to touch metal case → Big current surges to earth → This surge draws a large current through the live wire → Current melts fuse in live wire... → ...which isolates the appliance from the live

Circuit Breakers Have Some Advantages Over Fuses

1) Circuit breakers are an electrical safety device used in some circuits. Like fuses, they protect the circuit from damage if too much current flows.
2) When circuit breakers detect a surge in current in a circuit, they break the circuit by opening a switch.
3) A circuit breaker (and the circuit they're in) can easily be reset by flicking a switch on the device. This makes them more convenient than fuses — which have to be replaced once they've melted.
4) One common type of circuit breaker is a Residual Current Circuit Breaker (RCCB):
   a) Normally the same current flows through the live and neutral wires. If somebody touches the live wire, a current will flow through them to the earth. This means the neutral wire carries less current than the live wire. The RCCB detects this difference in current and cuts off the power by opening a switch.
   b) They also operate much faster than fuses — they break the circuit as soon as there is a current surge — no time is wasted waiting for the current to melt a fuse. This makes them safer.
   c) RCCBs even work for small current changes that might not be large enough to melt a fuse. Since even small currents could be fatal, this means RCCBs are more effective at protecting against electrocution.

Why are earth wires green and yellow — when mud's brown...

Electricity is very useful, but it can also be very dangerous. Make sure you know the risks.

Q1 State the wire of a plug that a fuse should be connected to. [1 mark]

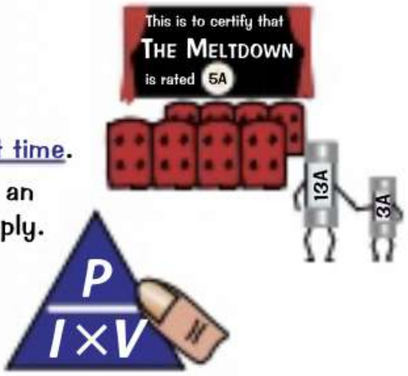
Energy and Power in Circuits

This page is all about how to cook toast... well, maybe not... but it's just as useful.

Resistors Get Hot When an Electric Current Passes Through Them

1) When there is an electric current in a resistor there is an energy transfer which heats the resistor.
2) This happens because the electrons collide with the ions in the lattice that make up the resistor as they flow through it. This gives the ions energy, which causes them to vibrate and heat up.
3) This heating effect increases the resistor's resistance — so less current will flow, or a greater voltage will be needed to produce the same current.
4) This heating effect can cause components in the circuit to melt — which means the circuit will stop working, or not work properly. Fuses use this effect to protect circuits — they melt and break the circuit if the current gets too high (see previous page).
5) The heating effect of an electric current can have other advantages. For example, it's ace if you want to heat something. Toasters contain a coil of wire with a really high resistance. When a current passes through the coil, its temperature increases so much that it glows and gives off infrared (heat) radiation which cooks the bread.

Electrical Power and Fuse Ratings



1) Electrical power is the rate at which an appliance transfers energy.
2) An appliance with a high power rating transfers a lot of energy in a short time.
3) This energy comes from the current flowing through it. This means that an appliance with a high power rating will draw a large current from the supply.
4) Power is measured in watts (W). The formula for electrical power is:

Electrical Power = Current × Voltage

5) Most electrical goods show their power rating and voltage rating.
6) Fuses have current ratings and should be rated as near as possible but just higher than the normal operating current.
7) To work out the fuse needed, you need to work out the current that the item will normally use.

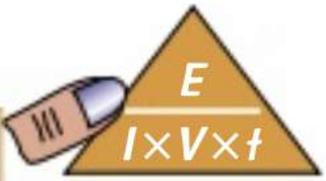
Example: A hair dryer is rated at 230 V, 1 kW. Find the fuse needed.
1 kW = 1000 W
$I = P/V = 1000/230 = 4.3$ A. Normally, the fuse should be rated just a little higher than the normal current, so a 5 amp fuse is ideal for this one.

The most common fuse ratings in the UK are 3 A, 5 A and 13 A.

Electrical Appliances Transfer Energy Electrically

1) The energy transferred by an appliance depends on the power of the appliance and how long it is on for (measured in seconds, s): Energy Transferred = Electrical Power × Time.
2) Using the equation above, the formula for energy transferred is:

Energy transferred = Current × voltage × time



Example: The motor in an electric toothbrush is attached to a 3 V battery. If a current of 0.8 A flows through the motor for 3 minutes, calculate the energy transferred by the motor.
Use $E = I \times V \times t = 0.8 \times 3 \times (3 \times 60) = 432$ J

Time needs to be in seconds.

Current = heat — so eat fruit cake when you're cold...

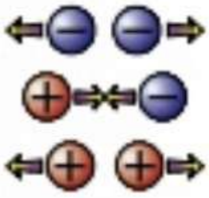
If a fuse's rating is too low, it will blow when you don't want it to. If it's too high, the fuse won't blow when it needs to.

Q1 Calculate the power of a lamp connected to a 230 V source with a 6.0 A current flowing through it. [2 marks]

Static Electricity

Static electricity is all about charges which are not free to move. This causes them to build up in one place and it often ends with a spark or a shock when they do finally move.

Like Charges Repel, Opposite Charges Attract



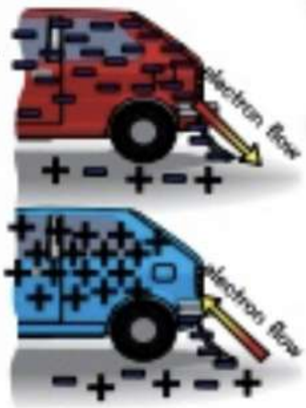
1) Two things with opposite electric charges are attracted to each other.
2) Two things with the same electric charge will repel each other.
3) These forces get weaker the further apart the two things are.

Conductors Conduct Charge — Insulators Don't

1) Materials that are electrical conductors conduct charge easily — a current can flow through them. They're usually metals, e.g. copper and silver.
2) Electrical insulators don't conduct charge very well — so a current can't flow. Examples include plastic and rubber.

A Static Charge Cannot Move

1) A static charge is a charge which builds up in one place and is not free to move. These are more common on insulators, where current cannot flow, rather than on conductors.
2) A common cause of static electricity is friction (see next page). When two insulating materials are rubbed together, electrons will be scraped off one and dumped on the other.
3) This'll leave a positive electrostatic charge on one and a negative electrostatic charge on the other.
4) Which way the electrons are transferred depends on the two materials involved.
5) Both +ve and −ve electrostatic charges are only ever produced by the movement of electrons. The positive charges definitely do not move! A positive static charge is always caused by electrons moving away elsewhere.
6) Static charges can occur on conductors too — cars often get a static charge on the outside because they've gained or lost electrons from the air rushing past them as they travel at high speeds.
7) A charged conductor can be discharged safely by connecting it to earth with a metal strap. The electrons flow down the strap to the ground if the charge is negative and flow up the strap from the ground if the charge is positive.



As Charge Builds Up, So Does the Voltage

1) As electric charge builds on an isolated object, the voltage between the object and the earth (which is at zero volts) increases.
2) If the voltage gets large enough, electrons can jump across the gap between the charged object and the earth — this is the spark.
3) They can also jump to any earthed conductor that is nearby — which is why you can get static shocks from clothes, or getting out of a car.
4) This usually happens when the gap is fairly small. (But not always — lightning is just a really big spark, see page 25.)

Static caravans — where electrons go on holiday...

Static electricity's great fun. You must have tried it — rubbing a balloon against your jumper and trying to get it to stick to the ceiling. It really works... well, sometimes. Bad hair days are caused by static too — it builds up on your hair, so your strands of hair repel each other. Which is nice...

Q1 Jake removes his jumper in a dark room. As he does so, he hears a crackling noise and sees tiny sparks of light between his jumper and his shirt. Explain the cause of this. [3 marks]

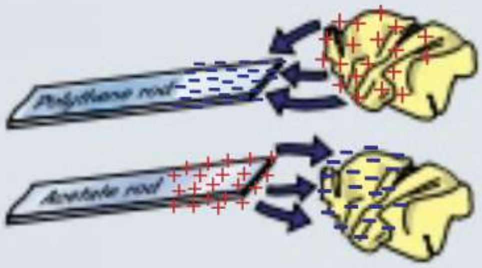
Static Electricity and Friction

You can test whether an object is charged, and whether the charge is positive or negative, by looking for attraction and repulsion.

Investigating Static Electricity

PRACTICAL

1) As you saw on the previous page, static charges can be caused by friction.
2) The classic examples of this are polythene and acetate rods being rubbed with a cloth duster, as shown in the diagrams. You can test these out for yourself in the lab.
3) When the polythene rod is rubbed with the duster, electrons move from the duster to the rod. The rod becomes negatively charged and the duster is left with an equal positive charge.
4) When the acetate rod is rubbed, electrons move from the rod to the duster. The duster becomes negatively charged and the rod is left with an equal positive charge.
5) You can confirm that these rods have become charged using the methods outlined below.

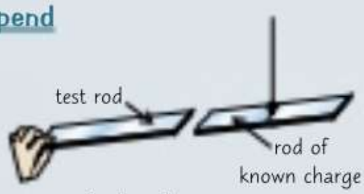


1) Gold-Leaf Electroscope

1) You can see whether a material is charged by using a gold-leaf electroscope.
2) A gold-leaf electroscope has a metal disc connected to a metal rod, at the bottom of which are attached two thin pieces of gold leaf.
3) When a rod with a charge is brought near to the disc of the electroscope, electrons will either be attracted to, or repelled from, the metal disc — depending on the charge of the rod.
4) This induces a charge in the metal disc, which in turn induces a charge in the gold leaves. Both gold leaves will have the same charge, so they will repel each other, causing them to rise.
5) When the rod is taken away, the gold leaves will discharge and fall again.
6) If the foil does not rise when the rod is brought near the disc, the rod is not charged.

2) Suspending a *Charged Rod*

1) Another way of testing whether a rod of material is charged is to suspend a rod with a known charge on a thread and see if there is repulsion or attraction when the rod you're testing is brought close to it.
2) If there is an attraction, then the test rod has the opposite charge to the suspended rod.
3) If there is a repulsion, then the test rod has the same charge as the suspended rod.



Van de Graaff Generators Make Your *Hair* Stand on End

A Van de Graaff generator is used to demonstrate electrostatic charges. It's made up of a rubber belt moving round plastic rollers underneath a metal dome. An electrostatic charge is built up on the metal dome as the belt goes round. If you stand on an insulated chair and place your hands on the dome, electrons will move between your body and the dome, giving your body a charge. The human body conducts charge, and like charges repel, so the charges will spread out as much as possible throughout your body. The charge is strong enough to make your hairs repel each other and stand on end.

This page is completely free of charge — hopefully...

Use these experiments to investigate how different things become charged depending on what they're made of.

P2 Q1 Describe one way of demonstrating that an insulating object is carrying a static charge. [2 marks] P2

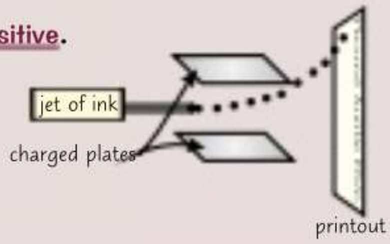
Static Electricity — Examples

They like asking you to give quite detailed examples in exams. Make sure you learn all these details.

Static Electricity Being Helpful:

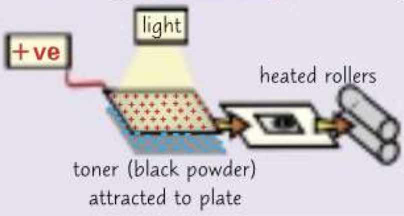
1) Inkjet Printer

1) Tiny droplets of ink are forced out of a fine nozzle, making them electrically charged.
2) The droplets are deflected as they pass between two metal plates. A voltage is applied to the plates — one is negative and the other is positive.
3) The droplets are attracted to the plate of the opposite charge and repelled from the plate with the same charge.
4) The size and direction of the voltage across each plate changes so each droplet is deflected to hit a different place on the paper.
5) Loads of tiny dots make up your printout. Clever.



2) Photocopier

1) The image plate is positively charged. An image of what you're copying is projected onto it.
2) Whiter bits of what you're copying make light fall on the plate and the charge leaks away in those places.
3) The charged bits attract negatively charged black powder, which is transferred onto positively charged paper.
4) The paper is heated so the powder sticks.
5) Voilà, a photocopy of your piece of paper (or whatever else you've shoved in there).



Static Electricity Being a Little Joker:

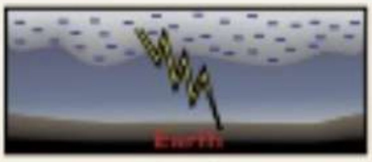
Clothing Crackles

When synthetic clothes are dragged over each other (like in a tumble dryer) or over your head, electrons get scraped off, leaving static charges on both parts, and that leads to the inevitable — attraction (they stick together) and little sparks / shocks as the charges rearrange themselves.

Static Electricity Being a Serious Problem:

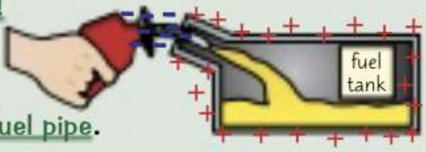
1) Lightning

Rain drops and ice bump together inside storm clouds, knocking off electrons and leaving the top of the cloud positively charged and the bottom of the cloud negative. This creates a huge voltage and a big spark.



2) The Fuel-Filling Nightmare

1) As fuel flows out of a filler pipe, static can build up.
2) This can easily lead to a spark and in dusty or fumy places — BOOM!
3) The solution: make the nozzles out of metal so that the charge is conducted away, instead of building up.
4) It's also good to have earthing straps between the fuel tank and the fuel pipe.



I know, I know — yet another shocking joke...

Lightning always chooses the easiest path to get to the ground — even if that means going through tall buildings and trees. That's why you should never put up an umbrella or fly a kite in a thunderstorm.

P2 Q1 Give an example of a device that uses static electricity. [1 mark] P2

Revision Questions for Section 2

And you've struggled through to the end of Section 2. Have a break, then test what you can remember.

- Try these questions and tick off each one when you get it right.
- When you've done all the questions for a topic and are completely happy with it, tick off the topic.

Circuit Properties (p.16) ☐

1) Explain what current, voltage and resistance are in an electric circuit. ☐
2) In a standard test circuit, where must the ammeter be placed? Where must the voltmeter be placed? ☐
3) What is the difference between a.c. and d.c.? ☐

Circuit Components (p.17-18) ☐

4) Calculate the resistance of a wire if the voltage across it is 12 V and the current through it is 2.5 A. ☐
5) Sketch typical current-voltage graphs for:
   a) a wire (at constant temperature),
   b) a resistor (at constant temperature),
   c) a filament lamp,
   d) a diode.
   Explain the shape of each graph. ☐
6) What can LEDs be used to indicate the presence of? ☐
7) Describe how the resistance of an LDR varies with light intensity. Give an application of an LDR. ☐

Series and Parallel Circuits (p.19) ☐

8) True or False? The current is the same everywhere in a series circuit. ☐
9) Why are parallel circuits often more useful than series ones? ☐

Electrical Safety and Energy in Circuits (p.20-22) ☐

10) If 80 C of charge is carried past a certain point in a wire in 2 s, how much current is flowing? ☐
11) Give the definition of a volt. ☐
12) Sketch a properly wired three-pin plug. ☐
13) What does it mean if an appliance is 'double insulated'? ☐
14) Explain how a fuse and earth wire work together in a plug. ☐
15) Explain how a Residual Current Circuit Breaker (RCCB) works. ☐
16) Give two advantages of using an RCCB instead of a fuse and an earthing wire. ☐
17) Why does the wire in a fuse melt when the current gets too high? ☐
18) Find the appropriate fuse (3 A, 5 A or 13 A) for these appliances:
    a) a toaster rated at 230 V, 1100 W   b) an electric heater rated at 230 V, 2000 W ☐
19) A light bulb has a voltage of 20 V across it and 7.2 kJ of energy is transferred to it electrically over a 2 minute period. What current flows through the bulb? ☐

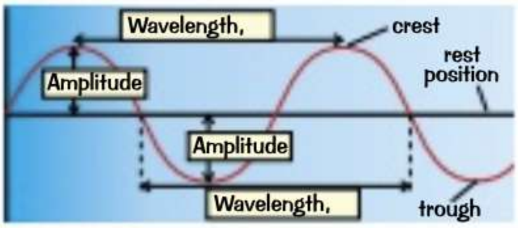
Static Electricity (p.23-25) ☐

20) Give an example of an electrical conductor and an electrical insulator. ☐
21) What causes the build-up of static electricity? Which particles move when static builds up? ☐
22) Describe how an acetate rod becomes electrically charged when it is rubbed with a duster. ☐
23) Give two examples of how static electricity can be dangerous. ☐

Waves — The Basics

We're constantly bombarded by waves (light, sound, heat)... and they've all got stuff in common.

All Waves Have Wavelength, Frequency, Amplitude and Speed



1) WAVELENGTH (λ) is the distance from one peak to the next.
2) FREQUENCY (f) is how many complete waves there are per second (passing a certain point). It's measured in hertz (Hz). 1 Hz is 1 wave per second.
3) AMPLITUDE is the height of the wave (from rest to crest).
4) The SPEED (v, for velocity) is, well, how fast the wave goes.
5) The PERIOD (T) is the time it takes (in s) for one complete wave to pass a point. E.g. a wave with period 0.002 s has a frequency of 1 ÷ 0.002 = 500 Hz.

$$f = \frac{1}{T}$$

Wave Speed = Frequency × Wavelength

1) You need to learn this equation — and practise using it.

Speed (m/s) = Frequency (Hz) × Wavelength (m) OR $v = f \times \lambda$

2) You won't always be asked for the speed though, so you might need this triangle too...

EXAMPLE: Find the frequency of a light wave with wavelength 1×10^{-7} m. (Speed of light = 3×10^{8} m/s.)
Using the triangle, frequency = speed ÷ wavelength = $(3 \times 10^{8}) \div (1 \times 10^{-7}) = 3 \times 10^{15}$ Hz.

3) Waves often have high frequencies which are given in awkward units like kHz or MHz: 1 kHz (kilohertz) = 1000 Hz, and 1 MHz (megahertz) = 1 000 000 Hz. For example, 900 MHz = 900 000 000 Hz.

Waves Can Be Transverse or Longitudinal

Most waves are TRANSVERSE:
1) Light and all other EM waves (see p.28).
2) A slinky spring wiggled up and down.
3) Waves on strings.
4) Ripples on water.

In TRANSVERSE waves the vibrations are at 90° to the DIRECTION ENERGY IS TRANSFERRED by the wave.

Some LONGITUDINAL waves are:
1) Sound and ultrasound.
2) Shock waves, e.g. some seismic waves.
3) A slinky spring when you push the end.

In LONGITUDINAL waves the vibrations are along the SAME DIRECTION as the wave transfers energy.

All Waves Transfer Energy and Information Without Transferring Matter

1) All waves carry and transfer energy in the direction they're travelling. E.g. microwaves in an oven make things warm up — their energy is transferred to the food you're cooking. Sound waves can make things vibrate or move, e.g. loud bangs can start avalanches.
2) Waves can also be used as signals to transfer information from one place to another — e.g. light in optical fibres, or radio waves travelling through the air. There's more on this on page 29.

Lambda nsak — waves & lentils...

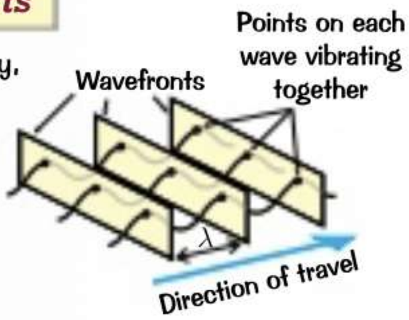
Make sure you remember that light is a transverse wave and that sound waves are longitudinal. It's important.

Q1 A sound wave in a material has a frequency of 19 kHz and a wavelength of 12.5 cm. Find its speed. [1 mark]

Wave Behaviour and EM Waves

The properties you saw on the last page can affect how waves behave. There's one type of wave which has very different properties at different wavelengths — we call these waves electromagnetic...

Two or More Waves Moving Together Have Wavefronts



1) Often when we talk about waves approaching an obstacle or boundary, there are multiple waves moving together in the same direction.
2) In this case it's useful to talk about wavefronts. Wavefronts are imaginary planes that cut across all the waves, connecting the points on adjacent waves which are vibrating together.
3) The distance between each wavefront is equal to one wavelength, i.e. each wavefront is at the same point in the cycle.

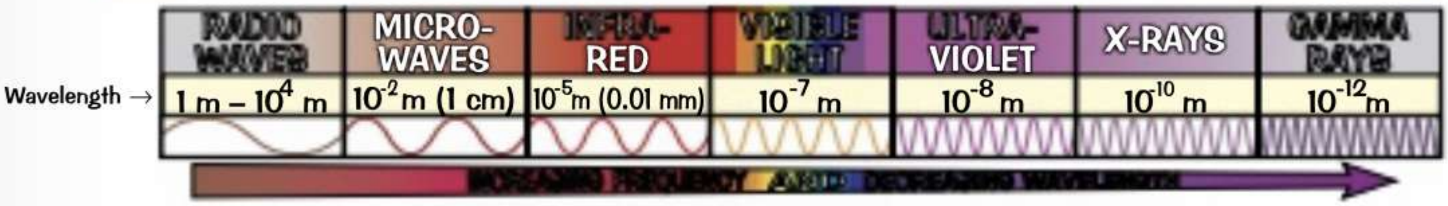
The Doppler Effect Makes Waves Longer or Shorter

1) The waves produced by a source which is moving towards or away from an observer will have a different wavelength than they would if the source were stationary.
2) This is because the wave speed is constant, so if the source is moving, it 'catches up' to the waves in front of it. This causes the wavefronts to bunch up in front of the moving source and spread out behind it.
3) The frequency of a wave from a source moving towards you will be higher and its wavelength will be shorter than the wave produced by the source.
4) The frequency of a wave from a source moving away from you will be lower and its wavelength will be longer than the wave produced by the source.

5) The faster a wave is moving away from you, the longer its wavelength will be.

There are Seven Types of Electromagnetic (EM) Waves

1) Electromagnetic (EM) waves with different wavelengths have different properties. They're grouped into seven types depending on their wavelength. But the types actually merge to form a continuous spectrum.



2) All types of EM radiation are transverse waves and travel at the same speed through free space (a vacuum).
3) The different colours of visible light depend on the wavelength — red has the longest wavelength (and lowest frequency) and violet has the shortest wavelength (and highest frequency).

Infrared and yellow and pink and green...

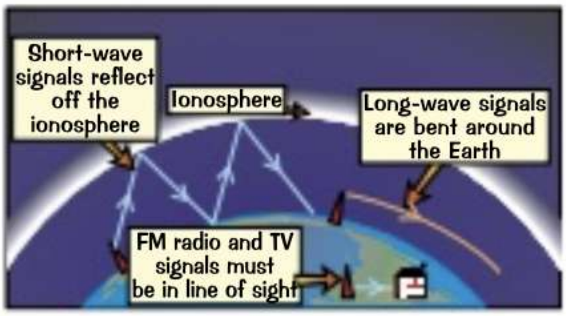
You need to know the colours in order of increasing frequency (decreasing wavelength) so just remember: Richard Of York Gave Battle In Vain (red, orange, yellow, green, blue, indigo, violet).

Q1 An ambulance travels towards you, passes and then continues travelling away. Compare the observed frequency of the siren before and after the ambulance passes. Give the name of this phenomenon. [2 marks]

Uses of Electromagnetic Waves

Waves are brilliant — there's so much you can do with a wave. So let's have a closer look at the uses of EM waves.

Radio Waves are Used Mainly for Communications



1) Radio waves are EM radiation with wavelengths longer than about 10 cm.
2) Long-wave radio (wavelengths of 1 – 10 km) can be transmitted a long way because long wavelengths are bent around the curved surface of the Earth.
3) Short-wave radio signals (wavelengths of about 10 m – 100 m) can also be received at long distances from the transmitter. That's because they are reflected from the ionosphere (a layer of the Earth's atmosphere).
4) The radio waves used for TV and FM radio broadcasting have very short wavelengths (10 cm – 10 m). To get reception, you must be in direct sight of the transmitter — the signal doesn't bend around hills.

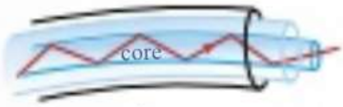
Microwaves are Used for Satellite Communication and Heating Food

1) Microwaves have a wavelength of around 1 – 10 cm, and can also be used for communication.
2) Satellite communication (including satellite TV signals and satellite phones) uses microwaves.
3) For satellite TV, the signal from a transmitter is transmitted into space, where it's picked up by the satellite receiver dish orbiting thousands of kilometres above the Earth. The satellite transmits the signal back to Earth where it's received by a satellite dish on the ground.
4) Mobile phone calls also travel as microwaves from your phone to the nearest transmitter.
5) Microwaves are also used for cooking. These microwaves are absorbed by the water molecules in the food. They penetrate a few centimetres into the food before being absorbed. The energy is then conducted or convected to other parts (see pages 43-44) of the food.

Infrared Radiation is Used for Heating and to Monitor Temperature

1) Infrared radiation (or IR) is also known as heat radiation. Electrical heaters radiate IR to keep us warm, and things like grills use IR to cook food.
2) IR is given out by all objects — the hotter the object, the more IR radiation it gives out.
3) The infrared radiation given out by objects can be detected in the dark of night by night-vision equipment. The equipment turns it into an electrical signal, which is displayed on a screen as a picture, allowing things which would otherwise be hidden in the dark (e.g. criminals on the run) to be seen.

Light Signals Can Travel Through Optical Fibres



1) As well as using it to look at things around us, visible light can be used for communication using optical fibres — which carry data over long distances as pulses of light.
2) Optical fibres work by bouncing waves off the sides of a very narrow core.
3) The pulse of light enters the fibre at a certain angle at one end and is reflected again and again until it emerges at the other end.
4) Optical fibres are increasingly being used for telephone and broadband internet cables. They're also used for medical purposes to 'see inside' the body without having to operate.

This is known as total internal reflection — see p. 35.

Microwaves — used for TV AND for TV dinners...

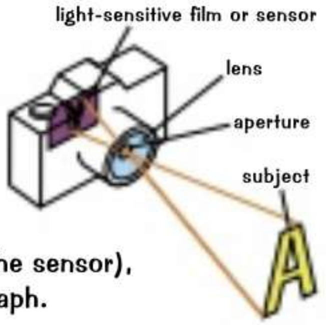
...and for texting your mum to ask her to record your favourite programme. See — I told you waves were ace.

Q1 Give two uses of infrared radiation. [2 marks]

Uses of Electromagnetic Waves

That's right — yet another page on the uses of EM waves. Visible light, ultraviolet, X-rays and gamma rays are the shortest waves in the spectrum, and we use them for all sorts of fancy stuff...

Visible Light is Also Useful for *Photography*



It sounds pretty obvious, but photography would be kinda tricky without visible light.

1) Cameras use a lens to focus visible light onto a light-sensitive film or sensor.
2) The lens aperture controls how much light enters the camera.
3) The shutter speed determines how long the film or sensor is exposed to the light.
4) By varying the aperture and shutter speed (and also the sensitivity of the film or the sensor), a photographer can capture as much or as little light as they want in their photograph.

Ultraviolet is Used in *Fluorescent Lamps*

1) Fluorescence is a property of certain chemicals, where ultraviolet radiation (UV) is absorbed and then visible light is emitted. That's why fluorescent colours look so bright — they actually emit light.
2) Fluorescent lights (like the ones you might have in your classroom) use UV radiation to emit visible light. They're safe to use as nearly all the UV radiation is absorbed by a phosphor coating on the inside of the glass which emits visible light instead.
3) Fluorescent lights are more energy-efficient (see page 40) than filament light bulbs.

The Sun also emits a lot of UV radiation — it can cause damage to skin cells (see p.31).

X-Rays Let Us See *Inside* Things

1) X-rays are used to view the internal structure of objects and materials, including our bodies — which is why they're so useful in medicine.
2) To make an X-ray image, X-rays are directed through the object or body onto a detector plate. The brighter bits are where fewer X-rays get through. This is a negative image.
3) Radiographers in hospitals take X-ray photographs to help doctors diagnose broken bones — X-rays pass easily through flesh but not through denser material like bones or metal.
4) Exposure to X-rays can cause mutations which lead to cancer, so radiographers and patients are protected as much as possible by lead aprons and shields, and exposure to the radiation is kept to a minimum.

Gamma Radiation Can be *Very Useful* For...

...Sterilising Medical Equipment

1) Gamma rays are used to sterilise medical instruments by killing all the microbes.
2) This is better than trying to boil plastic instruments, which might be damaged by high temperatures.

...Sterilising Food

1) Food can be sterilised in the same way as medical instruments — again killing all the microbes.
2) This keeps the food fresh for longer, without having to freeze it or cook it or preserve it some other way.
3) The food is not radioactive afterwards, so it's perfectly safe to eat.

Lights. Camera. Action...

You've probably got the idea by now that we use electromagnetic radiation an awful lot — much more even than the few examples covered on these pages. These are the uses you need to make sure you know for the exam though.

Q1 Suggest one advantage of using gamma rays to sterilise medical instruments instead of boiling them. [1 mark]

Dangers of Electromagnetic Waves

Okay, so you know how useful electromagnetic radiation can be — well, it can also be pretty dangerous. (So it'll probably be banned one of these days... sigh.)

Some EM Radiation Can be Harmful to People

When EM radiation enters living tissue — like you — it's often harmless, but sometimes it creates havoc.

1) Some EM radiation mostly passes through soft tissue without being absorbed — e.g. radio waves.
2) Other types of radiation are absorbed and cause heating of the cells — e.g. microwaves.
3) Some radiations can cause cancerous changes in living cells — e.g. gamma rays can cause cancer.

Higher Frequency EM Radiation is Usually More Dangerous

1) The effects of EM radiation depend on its frequency. The higher the frequency of EM radiation, the more energy it has and generally the more harmful it can be.
2) In general, waves with lower frequencies (like radio waves — which are harmless as far as we know) are less harmful than high frequency waves like X-rays and gamma rays.
3) From a safety point of view, it's how radiation affects human tissue that's most vital. You need to know how the body can be affected if exposed to too much of the following radiation:

MICROWAVES

Microwaves have a similar frequency to the vibrations of many molecules, and so they can increase these vibrations. The result is internal heating — the heating of molecules inside things (as in microwave ovens). Microwaves **HEAT HUMAN BODY TISSUE** internally in this way.

Microwave ovens need to have shielding to prevent microwaves from reaching the user.

INFRARED

The infrared (IR) range of frequencies can make the surface molecules of any substance vibrate — and like microwaves, this has a heating effect. But infrared has a higher frequency, so it carries more energy than microwave radiation. If the human body is exposed to too much infrared radiation, it can cause some nasty **SKIN BURNS**. You can protect yourself using insulating materials to reduce the amount of IR reaching your skin.

ULTRAVIOLET

UV radiation can **DAMAGE SURFACE CELLS** and cause **BLINDNESS**. Some frequencies of UV radiation are 'ionising' — they carry enough energy to knock electrons off atoms. This can cause cell mutation or destruction, and cancer.

You should wear sunscreen with UV filters whenever you're out in the sun, and stay out of strong sunlight to protect your skin from UV radiation.

GAMMA

Very high-frequency waves, such as gamma rays, are also ionising, and carry much more energy than UV rays. This means they can be much more damaging and they can penetrate further into the body. Like all ionising radiation, they can cause **CELL MUTATION** or destruction, leading to **TISSUE DAMAGE** or **CANCER**.

Radioactive sources of gamma rays should be kept in lead-lined boxes when not in use. When people need to be exposed to them, e.g. in medical treatment, the exposure time should be as short as possible.

I'll have the gamma and chips please, save the pineapple...

There's no point being paranoid — a little bit of sunshine won't kill you (in fact it'll probably do you good). But don't be daft... getting cancer from sunbathing for hours on end is no laughing matter. It's all a case of balancing the risks against the benefits, as well as keeping unnecessary exposure to a minimum.

Q1 Explain why gamma rays are more dangerous to humans than visible light. [2 marks]

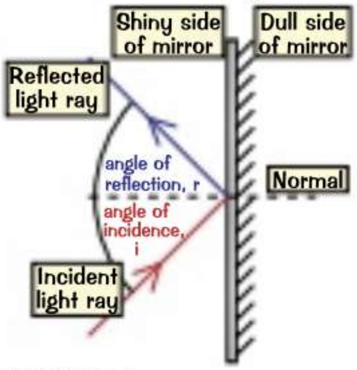
Reflection and Refraction of Waves

All waves can be reflected or refracted. Reflection happens when light bounces off an even surface, and refraction occurs when a wave slows down or speeds up at a boundary between two materials.

Reflection of Light Lets Us See Things

1) Visible light is a transverse wave (see page 27), like all EM waves.
2) Reflection of visible light is what allows us to see most objects. Light bounces off them into our eyes.
3) When light reflects from an uneven surface such as a piece of paper, the light reflects off at all different angles and you get a diffuse reflection.
4) When light reflects from an even surface (smooth and shiny like a mirror) then it's all reflected at the same angle and you get a clear reflection.
5) But don't forget, the LAW OF REFLECTION applies to every reflected ray:

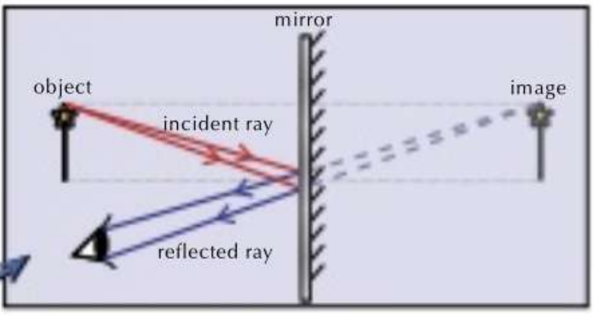
Angle of incidence = Angle of reflection



6) The normal is an imaginary line that's perpendicular (at right angles) to the surface at the point of incidence (the point where the wave hits the boundary). The normal is usually shown as a dotted line.
7) The angle of incidence is the angle between the incoming wave and the normal. The angle of reflection is the angle between the reflected wave and the normal.

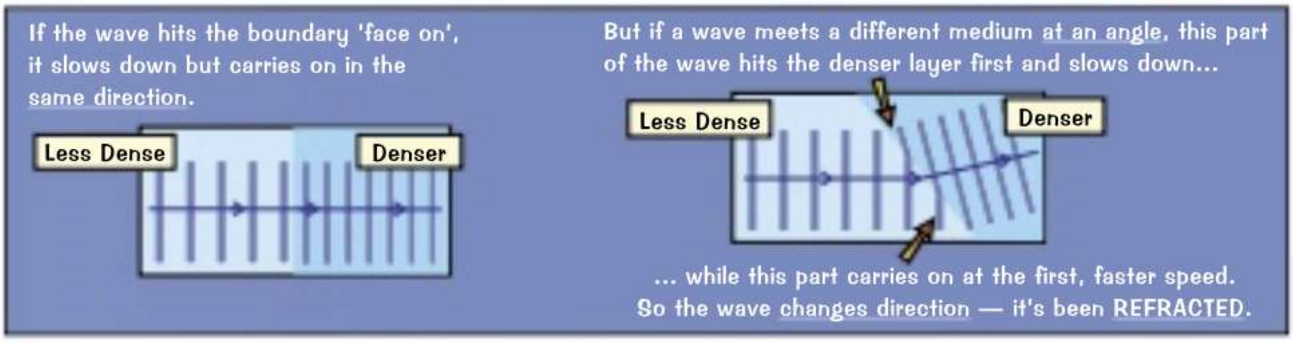
A ray diagram shows the path that a wave travels along. Rays are always drawn as straight lines.

8) You'll probably have gathered from years of looking in mirrors that they form images of whatever's in front of them.
9) Virtual images are formed when the light rays bouncing off an object onto a mirror are diverging, so the light from the object appears to be coming from a completely different place. This ray diagram shows how an image is formed in a PLANE MIRROR.



Waves Can be Refracted

1) Waves travel at different speeds in substances which have different densities. EM waves travel more slowly in denser media (usually). Sound waves travel faster in denser substances.
2) So when a wave crosses a boundary between two substances, from glass to air, say, it changes speed.



If the wave hits the boundary 'face on', it slows down but carries on in the same direction.

But if a wave meets a different medium at an angle, this part of the wave hits the denser layer first and slows down...

... while this part carries on at the first, faster speed. So the wave changes direction — it's been REFRACTED.

Plane mirrors — what pilots use to look behind them...

This stuff on reflection ain't too complicated — and it's easy marks in the exam. Make sure you can scribble down some nice, clear ray diagrams and you should be well on your way to a great mark.

Q1 A ray is incident on a plane mirror at an angle of incidence of 25°. What is the angle of reflection of the ray? [1 mark]

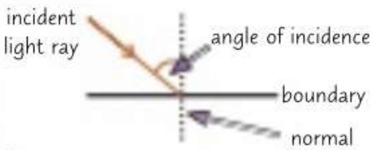
More About Refraction of Waves

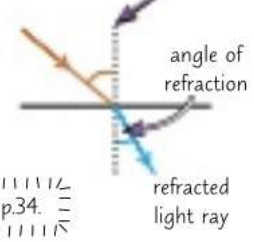
Didn't get your fill of refraction from the last page? Don't worry, we've got you covered...

Draw a Ray Diagram for a Refracted Wave

A ray diagram shows the path that a wave travels. You can draw one for a refracted light ray:

1) First, start by drawing the boundary between your two materials and the normal (a line that is at 90° to the boundary).
2) Draw an incident ray that meets the normal at the boundary.
3) The angle between the ray and the normal is the angle of incidence. (If you're given this angle, make sure to draw it carefully using a protractor.)
4) Now draw the refracted ray on the other side of the boundary. If the second material is denser than the first, the refracted ray bends towards the normal (like on the right). The angle between the refracted ray and the normal (the angle of refraction) is smaller than the angle of incidence.
5) If the second material is less dense, the angle of refraction is larger than the angle of incidence.



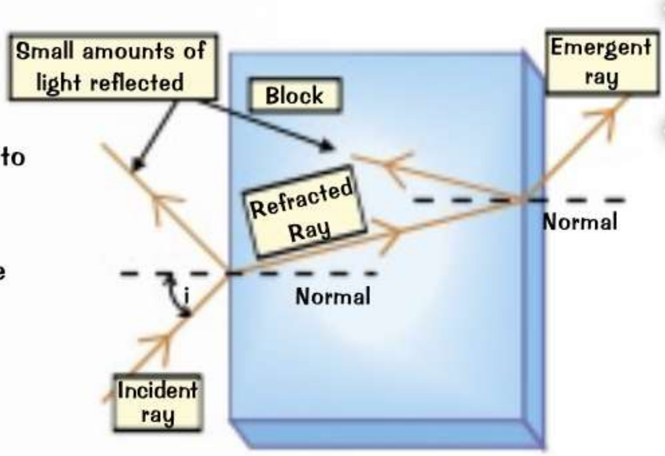


There are more ray diagrams on p.34.

Rays Passing Through a Glass Block are Refracted Twice

PRACTICAL

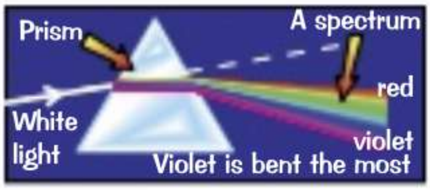
1) You can experiment with refraction using a light source and a rectangular block of a particular material (e.g. glass) resting on top of a piece of paper...
2) Shine a light ray at an angle into the block, as shown. Some of the light is reflected, but a lot of it passes through the glass and gets refracted as it does so.
3) Trace the incident and emergent rays onto the piece of paper and remove the block. You can draw in the refracted ray through the block by joining the ends of the other two rays with a straight line.
4) You should see that as the light passes from the air into the block (a denser medium), it bends towards the normal. This is because it slows down.
5) When the light reaches the boundary on the other side of the block, it's passing into a less dense medium. So it speeds up and bends away from the normal. (Some of the light is also reflected at this boundary.)
6) The light ray that emerges on the other side of the block is now travelling in the same direction it was to begin with — it's been refracted towards the normal and then back again by the same amount.



Triangular Prisms Disperse White Light

PRACTICAL

You'll get an interesting effect if you shine white light into a triangular prism. Different wavelengths of light refract by different amounts, so white light (which is a mixture of all visible frequencies) disperses into different colours as it enters a prism and the different wavelengths are refracted by different amounts. A similar effect happens as the light leaves the prism, which means you get a nice rainbow effect.



Denser media — lead newspapers...

Learn the straightforward rule: more dense materials slow light down, less dense materials speed it up.

Q1 A ray travels from a less dense material to a more dense one. The angle of incidence is 30°. The angle of refraction at the boundary is 20°. Sketch the ray diagram for this ray. [2 marks]

Refractive Index and Snell's Law

So you're totally happy with the last two pages. And you're sure about that. Good. Gets a bit hairy here...

Every Transparent Material Has a Refractive Index

1) The refractive index of a transparent material tells you how fast light travels in that material. The refractive index of a material is defined as:

$$\text{refractive index, } n = \frac{\text{speed of light in a vacuum, } c}{\text{speed of light in that material, } v} \qquad n = \frac{c}{v}$$

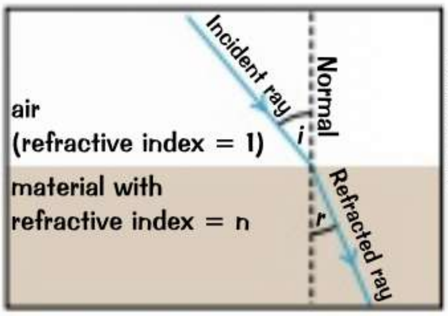
2) Light slows down a lot in glass, so the refractive index of glass is high (around 1.5). The refractive index of water is a bit lower (around 1.33) — so light doesn't slow down as much in water as in glass.
3) The speed of light in air is about the same as in a vacuum, so the refractive index of air is 1.00 (to 2 d.p.).
4) According to Snell's law, the angle of incidence, angle of refraction and refractive index are all linked...

Snell's Law Says...

When an incident ray passes into a material:

$$n = \frac{\sin i}{\sin r}$$

So if you know any two of n, i or r, you can work out the missing one.

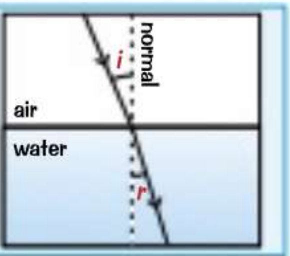


Remember, if a wave is travelling along (or parallel to) the normal when it crosses a boundary between materials, it doesn't refract.

EXAMPLE: A beam of light travels from air into water. The angle of incidence is 23°. Refractive index of water = 1.33. Calculate the angle of refraction to the nearest degree.

Using Snell's law, $\sin r = \frac{\sin i}{n} = \frac{\sin 23^\circ}{1.33} = 0.29...$

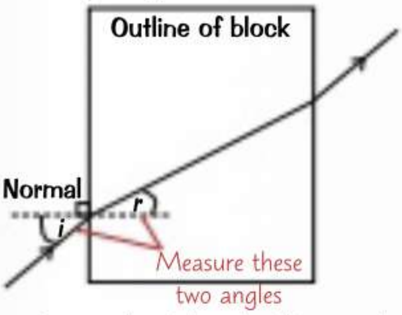
$r = \sin^{-1}(0.29...) = \underline{17^\circ}$



Find the Refractive Index of Glass Using a Glass Block

PRACTICAL

You need to be able to describe an experiment to find the refractive index of a glass block — it's pretty much the same as the rectangular block experiment on the last page.



The refractive index of glass should be around 1.5, so if you get a ridiculous answer then you've gone wrong somewhere.

1) Draw around a rectangular glass block on a piece of paper and direct a ray of light through it at an angle. Trace the incident and emergent rays, remove the block, then draw in the refracted ray between them.
2) You then need to draw in the normal at 90° to the edge of the block, at the point where the ray enters the block.
3) Use a protractor to measure the angle of incidence (i) and the angle of refraction (r), as shown. Remember — these are the angles made with the normal.
4) Calculate the refractive index (n) using Snell's law: $n = \frac{\sin i}{\sin r}$.
5) Et voilà — you should have found the refractive index of the block.

Revise refraction — but don't let it slow you down...

Make sure that you can scribble a decent version of the glass block diagram — if you know it, it's easy marks.

Q1 A ray of light passes into a glass block from the air. The angle of incidence is 34°. If the speed of light in the block is 1.9×10^8 m/s, calculate the angle of refraction of the ray. Use $c = 3.0 \times 10^8$ m/s. [3 marks]

Refractive Index and Critical Angles

Still with me? Great. There's one more angle you need to learn about...

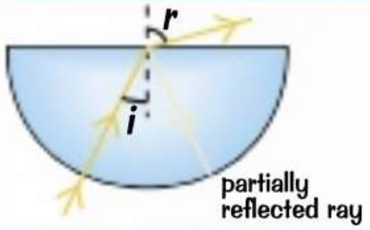
Use Semicircular Blocks to Show Total Internal Reflection

PRACTICAL

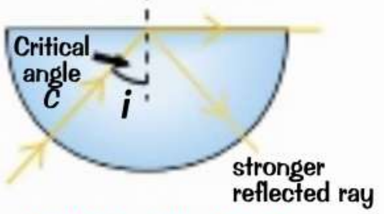
1) As you've just seen, light going from a material with a higher refractive index to a material with a lower refractive index speeds up and so bends away from the normal — e.g. when travelling from glass into air.
2) If you keep increasing the angle of incidence (*i*), the angle of refraction (*r*) gets closer and closer to 90°.
3) Eventually *i* reaches a critical angle *C* for which $r = 90°$. The light is refracted right along the boundary.
4) Above this critical angle, you get total internal reflection — no light leaves the medium.
5) An experiment to demonstrate this uses a semicircular block instead of a rectangular one. The incident light ray is aimed at the curved edge of the block so that it always enters at right angles to the edge. This means it doesn't bend as it enters the block, only when it leaves from the straight edge.
6) To investigate the critical angle, *C*, mark the positions of the rays and the block on paper and use a protractor to measure *i* and *r* for different angles of incidence. Record your results in a table.

IF THE ANGLE OF INCIDENCE (*i*) IS...

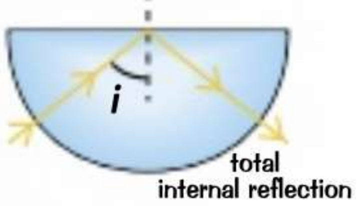
Remember — the angle of incidence and the angle of reflection are equal, and always measured from the normal.



...LESS than Critical Angle:
Most of the light passes out but a little bit is internally reflected.



...EQUAL to Critical Angle:
The emerging ray comes out along the surface. There's a lot of internal reflection.



...GREATER than Critical Angle:
No light comes out. It's all internally reflected, i.e. total internal reflection.

You Can Use Snell's Law to find Critical Angles

You can find the critical angle, *C*, of a material using this equation:

$$\sin C = \frac{1}{n}$$

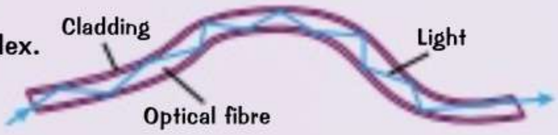
n is the refractive index of the material.

The higher the refractive index, the lower the critical angle. For water, *C* is 49°.

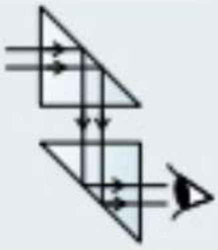
This equation comes from Snell's law that you saw on the last page — you don't need to know how, but you do need to learn both equations.

Optical Fibres and Prisms Use Total Internal Reflection

1) Optical fibres made of plastic or glass (see p.29) consist of a central core surrounded by cladding with a lower refractive index.
2) The core of the fibre is so narrow that light signals passing through it always hit the core-cladding boundary at angles higher than C — so the light is always totally internally reflected. It only stops working if the fibre is bent too sharply.



1) Total internal reflection also allows us to use prisms to see objects that aren't in our direct line of sight. This is how a periscope works.
2) The ray of light travels into one prism where it is totally internally reflected by 90°.
3) It then travels to another prism lower down and is totally internally reflected by another 90°.
4) The ray is now travelling parallel to its initial path but at a different height.



Critical angles are hard to please...

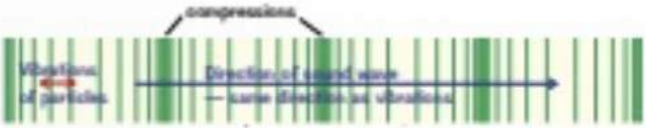
Total internal reflection only works as light tries to pass into something less dense (i.e. with a lower refractive index).

Q1 Calculate the critical angle for a material with a refractive index of 1.4. [2 marks]

Sound Waves

You hear sounds when vibrations reach your eardrums. What you hear depends on the properties of the sound wave that reaches you (as well as how much earwax you've got down your lugholes...).

Sound Travels as a Wave



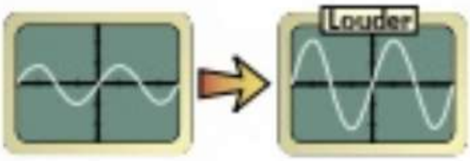
1) Sound waves are longitudinal waves caused by vibrating objects. The vibrations are passed through the surrounding medium as a series of compressions.
2) The sound may eventually reach someone's eardrum, at which point the person might hear it — the human ear is capable of hearing sounds with frequencies between 20 Hz and 20 000 Hz. (Although in practice some people can't hear some of the higher frequency sounds.)
3) Because sound waves are caused by vibrating particles, in general the denser the medium, the faster sound travels through it. This also means it can't travel through a vacuum, where there aren't any particles.
4) Sound generally travels faster in solids than in liquids, and faster in liquids than in gases.
5) Sound waves will be reflected by hard flat surfaces. Things like carpets and curtains act as absorbing surfaces, which will absorb sounds rather than reflect them.
6) Sound waves will also refract (change direction) as they enter different media. As they enter denser material, they speed up. (However, since sound waves are always spreading out so much, the change in direction is hard to spot under normal circumstances.)

An Oscilloscope Can Display Sound Waves

1) A sound wave receiver, such as a microphone, can pick up sound waves travelling through the air.
2) To display these sound waves, and measure their properties, you can plug the microphone into an oscilloscope. The microphone converts the sound waves to electrical signals.
3) An oscilloscope is a device which can display the microphone signal as a trace on a screen.
4) The appearance of the wave on the screen tells you whether the sound is loud or quiet, and high- or low-pitched. You can even take detailed measurements to calculate the frequency of the sound (see next page) by adjusting the settings of the display.

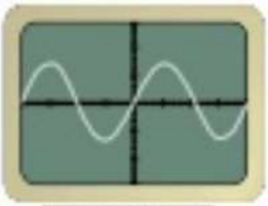
Loudness Increases with Amplitude

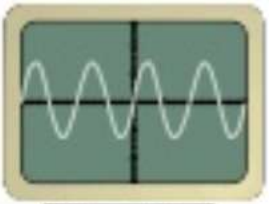
The greater the amplitude of a wave, the more energy it carries. In sound this means it'll be louder. Louder sound waves will also have a trace with a larger amplitude on an oscilloscope.

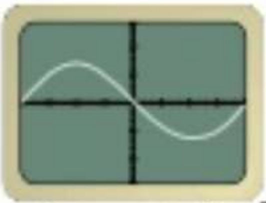


The Higher the Frequency, the Higher the Pitch

1) Frequency is the number of complete vibrations each second, and it's measured in hertz (Hz) — 1 Hz is equal to 1 vibration per second. Other common units are kHz (1000 Hz) and MHz (1 000 000 Hz).
2) You can compare the frequency of waves on an oscilloscope — the more complete cycles displayed on the screen, the higher the frequency (if the waves are being compared on the same scale — see the next page).
3) If the source of sound vibrates with a high frequency the sound is high-pitched, e.g. a squeaking mouse. If the source of sound vibrates with a low frequency the sound is low-pitched, e.g. a mooing cow.
4) The traces on the right are very important, so make sure you know them.


Original Sound


Higher pitched


Lower pitched


Higher pitched and louder

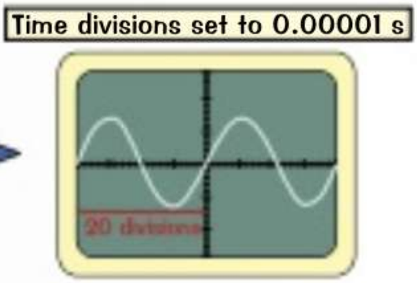
PRACTICAL

Sound Waves

All sounds have pitch and loudness. These can both be measured with a microphone and an oscilloscope.

Find the Period of a Wave on an Oscilloscope to get its Frequency

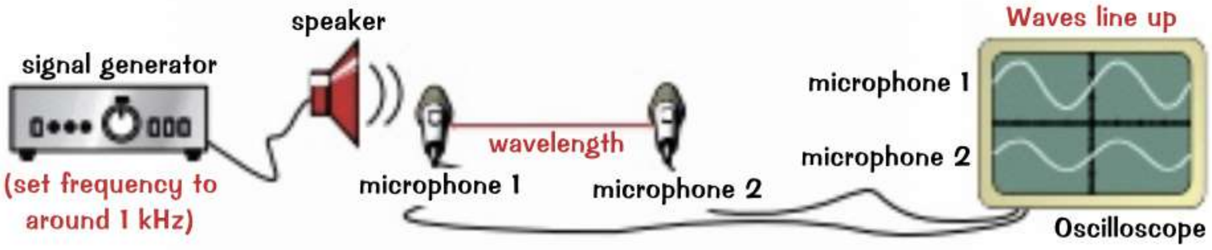
1) The horizontal axis on the oscilloscope display is time.
2) The time between each division on the scale can be adjusted to get a clear, readable trace. Here, each division has been set to show 0.00001 s.
3) Adjust the time division setting until the display shows at least 1 complete cycle, like this.
4) Read off the period — the time taken for one complete cycle.



- Here 1 cycle crosses 20 divisions, so period = 20 × 0.00001 s = 0.0002 s.
- Frequency = 1 ÷ period (see p.27)
  = 1 ÷ 0.0002 s = 5000 Hz = 5 kHz.

You Can Use an Oscilloscope to Measure the Speed of Sound

By attaching a signal generator to a speaker you can generate sounds with a specific frequency. You can use two microphones and an oscilloscope to find the wavelength of the sound waves generated:



1) The detected waves at each microphone can be seen as a separate wave on the oscilloscope.
2) Start with both microphones next to the speaker, then slowly move one away until the two waves are aligned on the display, but exactly one wavelength apart.
3) Measure the distance between the microphones to find the wavelength (λ).
4) You can then use the formula $v = f \times \lambda$ (see p. 27) to find the speed (v) of the sound waves passing through the air — the frequency (f) is whatever you set the signal generator to in the first place.

The two traces have the same frequency as they're detecting the same sound waves, but amplitude (loudness) is lost over distance.

The speed of sound in air is around 340 m/s, so check your results roughly agree with this.

You can measure the speed of sound in other ways...

For example, you can ask a friend to stand a long distance away (e.g. 100 m) and bang a drum (or do something that makes a loud bang). You can use a stopwatch to measure the time taken between you seeing the person make the noise, and when you hear it. Then use the $v = s/t$ equation (see page 1) to work out the speed.

P2

Q1 The density of the Earth's atmosphere decreases with altitude. A plane flying at a high altitude is heard from the ground. Describe and explain what happens to the speed of a sound wave as it travels from the plane to the ground. [2 marks]

Q2 A signal generator connected to a speaker is used to produce sound waves at a frequency of 560 Hz. If the speed of sound is roughly 340 m/s, calculate the approximate wavelength of the sound waves. [2 marks]

Revision Questions for Section 3

Phew, hurrah, yay — made it to the end of this section. Now it's time to get stuck into some revision questions...

- Try these questions and tick off each one when you get it right.
- When you've done all the questions for a topic and are completely happy with it, tick off the topic.

Wave Basics (p.27-28) ☐

1) Draw a diagram to illustrate frequency, wavelength and amplitude. ☐

2) What is the formula to calculate the frequency of a wave from the period? ☐

3) Find the frequency of a wave with wavelength 0.3 cm and speed 150 m/s. ☐

4) What is the main difference between a transverse wave and a longitudinal wave? ☐

5) What is the Doppler effect? ☐

6) Write down all seven types of EM radiation in order of increasing frequency and decreasing wavelength. ☐

7) Write down all the colours of visible light in order of increasing frequency and decreasing wavelength. ☐

Electromagnetic Waves (p.29-31) ☐

8) Describe one common use of each of the seven types of EM waves. ☐

9) Which is generally more hazardous — low frequency or high frequency EM radiation? ☐

10) Describe the harmful effects on the human body that can be caused by microwaves, infrared, UV and gamma rays. ☐

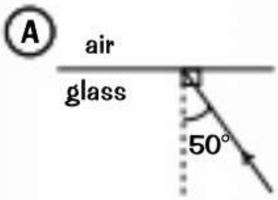
Reflection and Refraction (p.32-35) ☐

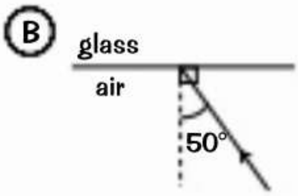
11) A ray of light hits the surface of a mirror at an incident angle of 10° to the normal. What is the angle of reflection for the ray of light? ☐

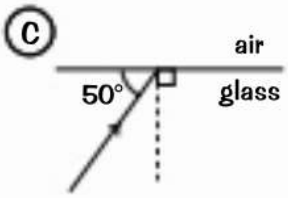
12) Draw a diagram to show the path of a ray of light that travels from air, enters a rectangular block of glass, then exits the block back into air on the other side (use an angle of incidence larger than 0°). ☐

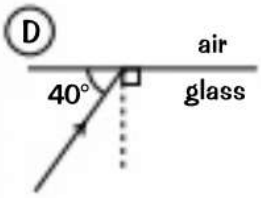
13) a) Write down Snell's law.
  b) A beam of light travelling through air enters a material with $i = 30°$. It refracts so that $r = 20°$. What is the refractive index of the material? ☐

14) In which of the cases A to D below would the ray of light be totally internally reflected? (The critical angle for glass is approximately 42°.) ☐









15) Give one practical use of total internal reflection. ☐

Sound Waves (p.36-37) ☐

16) True or false? Sound waves are longitudinal waves. ☐

17) This is a diagram of a sound wave displayed on an oscilloscope.
  a) What is happening to the loudness of the sound?
  b) What is happening to the pitch of the sound? ☐

18) Explain how you would find the frequency of a wave from an oscilloscope display. ☐

19) Describe an experiment to measure the speed of sound in air. ☐

Conservation of Energy

I hope you're feeling lively — this module is all about energy. The main thing to always remember about energy is that you can never make it or lose it — you just transfer it from one store to another.

Energy is Transferred Between Energy Stores

Energy can be held in different stores. Here are the stores you need to learn, plus examples of objects with energy in each of these stores:

1) KINETIC............................ — anything moving has energy in its kinetic energy store.
2) THERMAL.......................... — any object — the hotter it is, the more energy it has in this store.
3) CHEMICAL......................... — anything that can release energy by a chemical reaction, e.g. food, fuels.
4) GRAVITATIONAL POTENTIAL... — anything in a gravitational field (i.e. anything which can fall).
5) ELASTIC POTENTIAL............ — anything stretched, like springs and rubber bands.
6) ELECTROSTATIC.................. — e.g. two charges that attract or repel each other.
7) MAGNETIC......................... — e.g. two magnets that attract or repel each other.
8) NUCLEAR.......................... — atomic nuclei release energy from this store in nuclear reactions.

Energy can be transferred between stores in four main ways:

Mechanically — an object moving due to a force acting on it, e.g. pushing, pulling, stretching or squashing.
Electrically — a charge moving through a potential difference, e.g. charges moving round a circuit.
By heating — energy transferred from a hotter object to a colder object, e.g. heating a pan of water on a hob.
By radiation — energy transferred e.g. by light/sound waves, e.g. energy from the Sun reaching Earth as light.

There is a Principle of Conservation of Energy

There are plenty of different stores of energy, but energy always obeys the principle below:

Energy can be stored, transferred between stores, and dissipated — but it can never be created or destroyed. The total energy of a closed system has no net change.

A closed system is just a system (a collection of objects) that can be treated completely on its own, without any matter being exchanged with the surroundings.

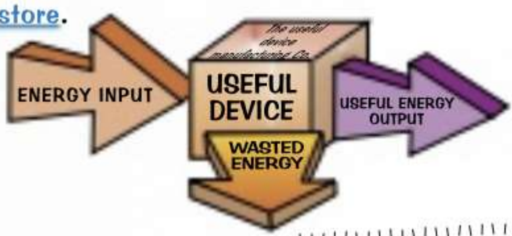
Dissipated is a fancy way of saying the energy is spread out and lost.

Most Energy Transfers Involve Some Losses, Often by Heating

1) Another important principle you need to know is:

Energy is only useful when it is transferred from one store to a useful store.

2) Useful devices can transfer energy from one store to a useful store.
3) However, some of the input energy is always lost or wasted, often to thermal energy stores by heating. For example, a motor will transfer energy to its kinetic energy store (useful), but will also transfer energy to the thermal energy stores of the motor and the surroundings (wasted).



4) The law of conservation of energy means that:
total energy input = useful energy output + wasted energy.
5) The less energy that's wasted, the more efficient the device is said to be.

The amount of energy wasted can often be reduced — see page 45.

Energy can't be created or destroyed — only talked about a lot...

This is important, so remember it. Energy can only be transferred to a different store, never destroyed.

Q1 Give the four main ways that energy can be transferred. [1 mark]

Efficiency

So energy is transferred between different stores. But not all of the energy is transferred to useful stores.

You can Calculate the Efficiency of an Energy Transfer

The efficiency of any device is defined as:

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy output}} \times 100\%$$

The total energy output will be the same as the total energy input, because of the principle of conservation of energy (see p.39).

You should give efficiency as a percentage, i.e. 75%.

All devices have an efficiency, but because some energy is always wasted, the efficiency can never be equal to or higher than 100%.

How to Use the Formula — Nothing to It

1) You find how much energy is supplied to a machine — the total energy INPUT. This equals the total energy OUTPUT.
2) You find how much useful energy the machine delivers — the useful energy OUTPUT. An exam question either tells you this directly or tells you how much is wasted.
3) Either way, you get those two important numbers and then just divide the smaller one by the bigger one, then multiply by 100, to get a value for efficiency somewhere between 0 and 100%. Easy.

Example: A toaster transfers 216 000 J of energy electrically from the mains. 84 000 J of energy is transferred to the bread's thermal energy store. Calculate the efficiency of the toaster.

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy output}} \times 100\%$$

$$= \frac{84\,000}{216\,000} \times 100 = 38.888... = \underline{39\%} \text{ (to 2 s.f.)}$$

4) The other way they might ask it is to tell you the efficiency and the total energy output and ask for the useful energy output, or they could tell you the efficiency and useful energy output and ask for the total energy output. You need to be able to swap the formula round.

We Generally Can't Do Anything Useful with Wasted Energy

1) The wasted energy that's output by a device is transferred to less useful stores — normally by heating, or by light or sound. As the energy is transferred away from the device to its surroundings, the energy often spreads out and becomes less concentrated — we say it dissipates.

   For example, a pan of water on a hob — the hob will transfer energy to the water, but some energy will be dissipated to the surrounding air by heating.

2) According to the principle of conservation of energy (see page 39), the total amount of energy stays the same. So the energy is still there, but it can't be easily used or collected back in again.

Make sure your revising efficiency is high...

So one really important thing to take from here — devices that transfer energy from one store to other stores will always transfer energy to stores that aren't useful. And when I say always, I mean always. Always. (Always.)

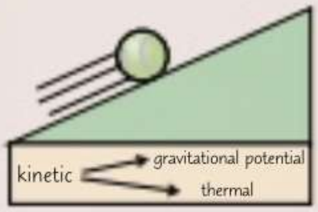
Q1 An electrical device wastes 420 J of energy when it has an input energy of 500 J. Calculate the efficiency of the device. [3 marks]

Energy Transfers

More! More! Tell me more about energy transfers please! OK, since you insist:

You Need to be Able to Describe Energy Transfers

In the exam, they can ask you about any device or energy transfer system they feel like. So it's no good just learning the examples here and on the next page — you need to understand the patterns, and analyse how energy moves between stores in different situations.

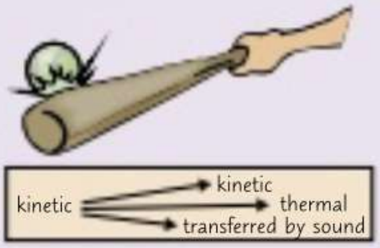


A BALL ROLLING UP A SLOPE:

Energy is transferred mechanically from the kinetic energy store of the ball to its gravitational potential energy store. Some energy is transferred mechanically to the thermal energy stores of the ball and the slope (due to friction), and then by heating to the thermal energy stores of the surroundings — this energy is wasted.

A BAT HITTING A BALL:

Some energy is usefully transferred mechanically from the kinetic energy store of the bat to the kinetic energy store of the ball. The rest of the energy is wasted. Some energy in the kinetic energy store of the bat is transferred mechanically to the thermal energy stores of the bat, the ball and their surroundings. The remaining energy is carried away by sound.

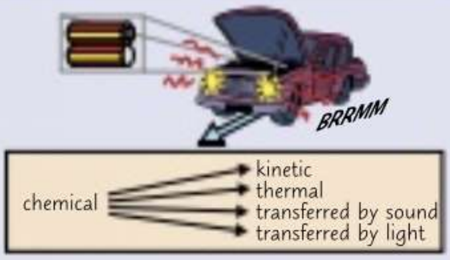


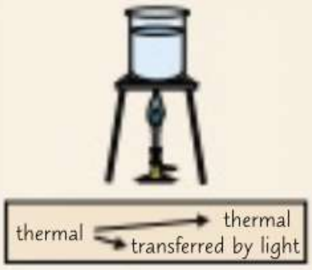
AN ELECTRIC KETTLE BOILING WATER:

Energy is transferred electrically from the mains to the thermal energy store of the kettle's heating element. It is then transferred by heating to the thermal energy store of the water. Some energy is wasted, and transferred by heating from the thermal energy stores of the heating element and the water to the thermal energy stores of the surroundings.

A BATTERY-POWERED TOY CAR:

Energy is usefully transferred electrically from the chemical energy store of the battery to the kinetic energy store of the car and carried away by light from the headlights. Wasteful energy transfers also occur, to thermal energy stores of the car and surroundings, and wastefully carried away by sound.





A BUNSEN BURNER AND BEAKER:

Energy is usefully transferred by heating from the chemical energy store of the gas to the thermal energy stores of the beaker and the water. Energy is also wastefully transferred by heating to the thermal energy stores of the stand and the surroundings. Some energy is also carried away by light.

Revise this — it won't be wasted energy...

Energy stores pop up everywhere in physics, the pesky scoundrels — make sure you've got to grips with them.

Q1 Describe the energy transfers for a falling ball landing on the ground without bouncing. [3 marks]

Q2 Describe the energy transfers that occur when a piece of wood is burning. [2 marks]

Sankey Diagrams

This is another opportunity for a MATHS question. Fantastic.
So best prepare yourself — here's what those Sankey diagrams are all about...

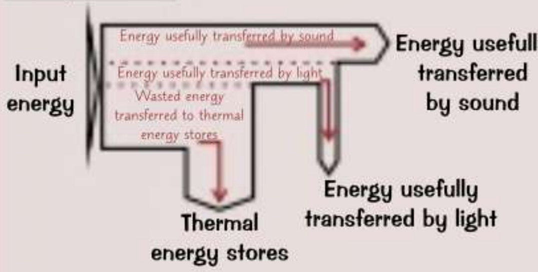
The Thickness of the Arrow Represents the Amount of Energy

The idea of Sankey (energy transformation) diagrams is to make it easy to see at a glance how much of the input energy is being usefully employed compared with how much is being wasted.

The thicker the arrow, the more energy it represents — so you see a big thick arrow going in, then several smaller arrows going off it to show the different energy transformations taking place.

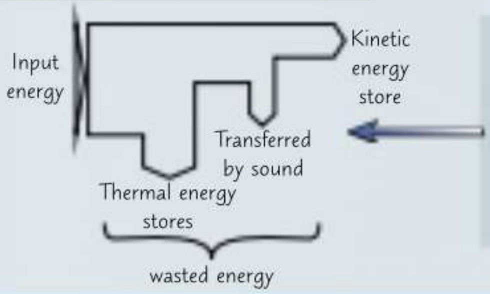
You can have either a little sketch or a properly detailed diagram where the width of each arrow is proportional to the number of joules it represents.

Example — TV:



Example — Sankey Diagram for a Simple Motor:

HERE'S THE SKETCH VERSION:



You don't know the actual amounts, but you can see that most of the energy is being wasted, and that it's mostly wasted as heat.

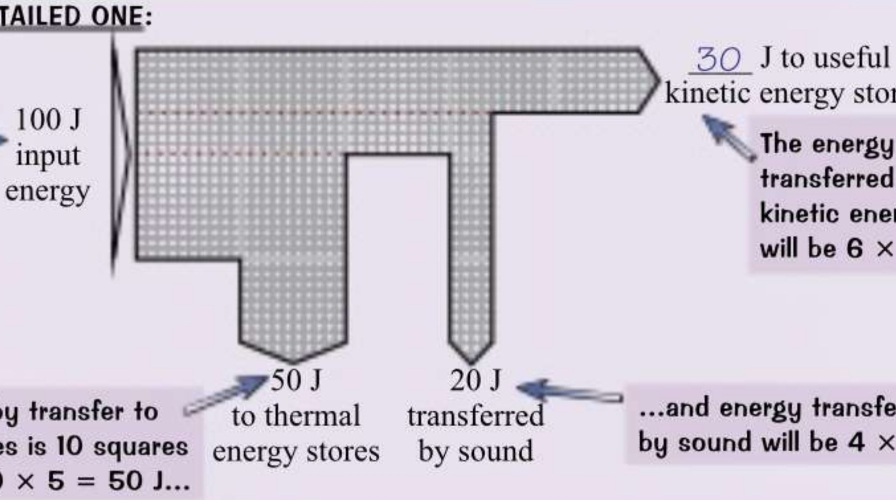
EXAM QUESTIONS:

With sketches, you might be asked to compare two different devices and say which is more efficient. You generally want to be looking for the one with the thickest useful energy arrow(s).

AND HERE'S THE DETAILED ONE:

100 J is 20 squares wide...

...so each square represents 100 ÷ 20 = 5 J.



The energy usefully transferred to the kinetic energy store will be 6 × 5 = 30 J.

The energy wasted by transfer to thermal energy stores is 10 squares wide, so that'll be 10 × 5 = 50 J...

...and energy transferred away by sound will be 4 × 5 = 20 J.

EXAM QUESTIONS:

In an exam, the most likely question you'll get about detailed Sankey diagrams is filling in one of the numbers or calculating the efficiency. The efficiency is straightforward enough if you can work out the numbers (see p.40).

Don't waste energy — turn the TV off while you revise...

If they ask you to draw your own Sankey diagram in the exam, if they don't give you the figures, a sketch is all they'll expect. Just give a rough idea of where the energy goes. E.g. a filament lamp turns most of the input energy into heat.

Q1 Sketch the Sankey diagram of a battery-powered torch. [2 marks]

Energy Transfer by Heating

Energy tends to be transferred away from a hotter object to its cooler surroundings.

Energy Transfer by Heating can Happen in Three Different Ways

1) Energy can be transferred by heating through radiation, conduction or convection.
2) Thermal radiation is the transfer of energy by heating by infrared electromagnetic waves (see below).
3) Conduction and convection are energy transfers that involve the transfer of energy by particles.
4) Conduction is the main form of energy transfer by heating in solids (see below).
5) Convection is the main form of energy transfer by heating in liquids and gases (see the next page).
6) Emission of thermal radiation occurs in solids, liquids and gases. Any object can both absorb and emit thermal radiation, whether or not conduction or convection are also taking place.
7) The bigger the temperature difference, the faster energy is transferred between the thermal energy stores of a body and its surroundings. Kinda makes sense.

Thermal Radiation Involves Emission of Electromagnetic Waves

Thermal radiation can also be called infrared (IR) radiation, and it consists purely of electromagnetic waves of a certain range of frequencies. It's next to visible light in the electromagnetic spectrum (see p.28).

1) All objects are continually emitting and absorbing infrared radiation.
2) An object that's hotter than its surroundings emits more radiation than it absorbs (as it cools down). And an object that's cooler than its surroundings absorbs more radiation than it emits (as it warms up).
3) You can feel this radiation if you stand near something hot like a fire.
4) Some colours and surfaces absorb and emit radiation better than others — see page 45 for more on this.

Conduction — Occurs Mainly in Solids

In a solid, the particles are held tightly together. So when one particle vibrates, it collides with other particles nearby and the vibrations quickly pass from particle to particle.

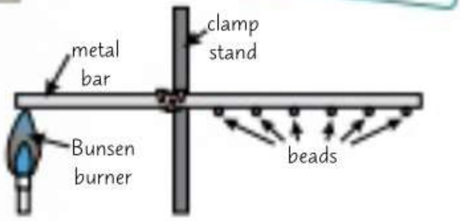
Thermal conduction is the process where vibrating particles transfer energy from their kinetic energy store to the kinetic energy stores of neighbouring particles.

This process continues throughout the solid and gradually some of the energy is passed all the way through the solid, causing a rise in temperature at the other side of the solid. It's then usually transferred to the thermal energy stores of the surroundings (or anything else touching the object).

You Can do an Experiment to Demonstrate Conduction

PRACTICAL

1) Attach beads at regular intervals (e.g. every 5 cm) to one half of a long (at least 30 cm) metal bar using wax.
2) Hold the metal bar in a clamp stand, and, using a Bunsen burner, heat the side of the bar with no beads attached from the very end.
3) As time goes on, energy is transferred along the bar by conduction and the temperature increases along the rod.
4) The wax holding the beads in place will gradually melt and the beads will fall as the temperature increases, starting with the bead closest to the point of heating. This illustrates conduction.



Transferring heat between bodies — not as much fun as it sounds...

Of the three energy transfer methods on this page, radiation is the only one that works through a vacuum, as it doesn't rely on there being any particles about. And that's how we can get heat from the Sun across the vacuum of space.

Q1 Name the main form of energy transfer by heating in a solid. [1 mark]

Convection

Gases and liquids are usually free to slosh about — and that allows them to transfer energy by convection, which is a much more effective process than conduction.

Convection of Heat — Liquids and Gases Only

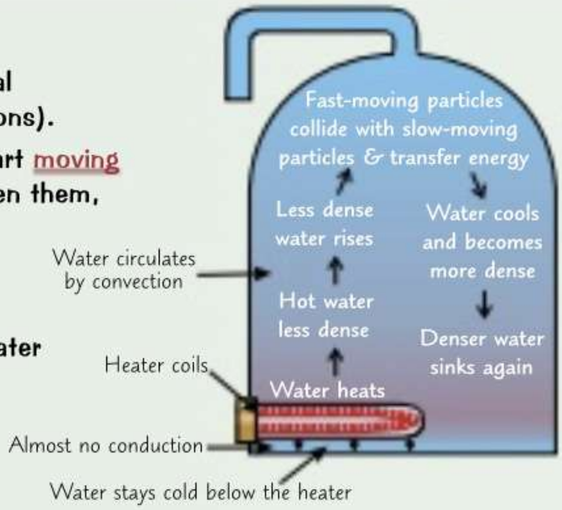
Convection occurs when the more energetic particles move from the hotter region to the cooler region — and transfer energy as they do.

This is how immersion heaters in kettles and hot water tanks and (unsurprisingly) convector heaters work. Convection simply can't happen in solids because the particles can't move (apart from vibrating, see page 54).

The Immersion Heater Example

In a bit more detail:

1) Energy is transferred from the heater coils to the thermal energy store of the water by conduction (particle collisions).
2) The particles near the coils get more energy, so they start moving around faster. This means there's more distance between them, i.e. the water expands and becomes less dense.
3) This reduction in density means that hotter water tends to rise above the denser, cooler water.
4) As the hot water rises it displaces (moves) the colder water out of the way, making it sink towards the heater coils.
5) This cold water is then heated by the coils and rises — and so it goes on. You end up with convection currents going up, round and down, circulating the energy through the water.



Note that convection is most efficient in roundish or squarish containers, because they allow the convection currents to work best. Shallow, wide containers or tall, thin ones just don't work quite so well.

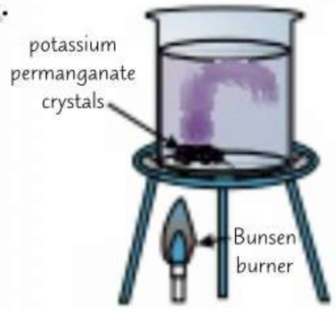
Also note that because the hot water rises (because of the lower density) you only get convection currents in the water above the heater. The water below it stays cold because there's almost no conduction.

CONVECTION CURRENTS are all about CHANGES IN DENSITY. Remember that.

You Can See Convection Currents Using Coloured Crystals

PRACTICAL

1) Place some purple potassium permanganate crystals in a beaker of cold water. Aim to put the crystals to one side of the beaker.
2) Using a Bunsen burner, gently heat the side of the beaker with the crystals at the bottom.
3) As the temperature of the water around the potassium permanganate crystals increases, they begin to dissolve, forming a bright purple solution.
4) This purple solution is carried through the water by convection, and so traces out the path of the convection currents in the beaker.



You've got to love that experiment with the purple crystals...

Radiators rely on convection currents to heat a room. The radiator heats the air around it, causing it to rise, and cooler air from elsewhere in the room flows in to fill the gap, where it is then heated by the radiator, and so on and so on.

Q1 Why does hot fluid rise in a convection current? [1 mark]

More Energy Transfers by Heating

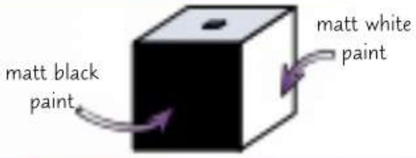
Energy transfer's great... unless you're the one losing energy. But never fear, there are things you can do to reduce the energy transferred away by radiation, convection and conduction.

You Can Reduce the Rate of Energy Transfer

1) All objects have a thermal conductivity — it describes how well an object transfers energy by conduction. Materials with a high thermal conductivity transfer energy between their particles quickly.
2) So, to reduce energy transfers away from a system by conduction, use materials with low thermal conductivity.
3) To reduce convection, you need to stop the fluid moving, and prevent convection currents from forming.
4) Insulation uses both of these techniques to reduce energy transfers.
5) Insulation such as clothes, blankets and foam cavity wall insulation all work by trapping pockets of air. The air can't move so the energy has to conduct very slowly through the pockets of air, as well as the material in between, both of which have a low thermal conductivity.
6) Some colours and surfaces will absorb and emit IR radiation better than others. For example, a black surface is better at absorbing and emitting radiation than a white one, and a matt (dull) surface is better at absorbing and emitting radiation than a shiny one.
7) So to reduce the energy transfers away from an object by thermal radiation, the object should be designed with a surface that is a poor emitter (e.g. shiny and white).

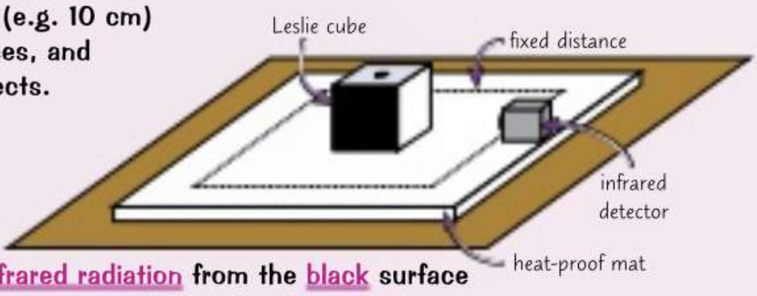
You Can Investigate Emission of Thermal Radiation With a Leslie Cube

A Leslie cube is a hollow, watertight, metal cube made of e.g. aluminium, whose four vertical faces have different surfaces (for example, matt black paint, matt white paint, shiny metal and dull metal). You can use them to investigate infrared (IR) emission by different surfaces:



PRACTICAL

1) Place an empty Leslie cube on a heat-proof mat.
2) Boil water in a kettle and fill the Leslie cube with boiling water.
3) Wait a while for the cube to warm up, then hold a thermometer against each of the four vertical faces of the cube. You should find that all four faces are the same temperature.
4) Hold an infrared detector a set distance (e.g. 10 cm) away from one of the cube's vertical faces, and record the amount of IR radiation it detects.
5) Repeat this measurement for each of the cube's vertical faces. Make sure you position the detector at the same distance from the cube each time.



6) You should find that you detect more infrared radiation from the black surface than the white one, and more from the matt surfaces than the shiny ones.
7) As always, you should do the experiment more than once, to make sure your results are repeatable (p.81).
8) It's important to be careful when you're doing this experiment. Don't try to move the cube when it's full of boiling water — you might burn your hands. And be careful if you're carrying a full kettle — your mate won't thank you if you spill boiling water into their bag (or down their back).

You can also investigate how absorption depends on surface. One way is to stick ball bearings to the back of two different surfaces with wax and see which one falls off first when the surfaces are placed equal distances from a bunsen burner.

Bundle your brew in newspaper to stop it going cold...

Have a go at naming as many methods for reducing energy transfers as you can, then try this question.

Q1 Why would hot water in a black mug cool down faster than if the mug was white? [2 marks]

Work and Power

Whenever I think of power, I have to stop myself from plotting world domination whilst stroking a cat.

'Work Done' is Just 'Energy Transferred'

When a force moves an object through a distance, WORK IS DONE on the object and ENERGY IS TRANSFERRED.

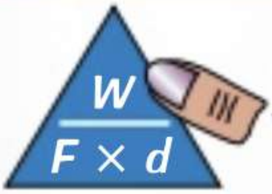
1) To make something move, some sort of force needs to act on it. The thing applying the force needs a source of energy (like fuel or food).
2) The force does 'work' to move the object and energy is transferred mechanically from one store to another (p.39).
3) Whether energy is transferred 'usefully' (e.g. lifting a load) or is 'wasted' (p.39), you can still say that 'work is done'. Just like Batman and Bruce Wayne, 'work done' and 'energy transferred' are indeed 'one and the same'.

When you push something along a rough surface (like a carpet) you are doing work against frictional forces. Energy is being transferred to the kinetic energy store of the object because it starts moving, but some is also being transferred to thermal energy stores due to the friction. This causes the overall temperature of the object to increase. (Like rubbing your hands together to warm them up.)

And Another Formula to Learn...

Work done = Force × Distance moved

This formula only works if the force is in exactly the same direction as the movement.



Whether the force is friction or weight or tension in a rope, it's the same equation. To find how much work has been done (in joules), you just multiply the force in newtons by the distance moved in metres. Easy as that. I'll show you...

Example: Some hooligan kids drag an old tractor tyre 5 m over flat ground. They pull with a total force of 340 N. Find the work done.

$W = F \times d = 340 \times 5 = 1700$ J. Phew — easy peasy isn't it?

Power is the 'Rate of Doing Work' — i.e. How Much per Second

1) Power is a measure of how quickly work is being done. As work done = energy transferred, you can define power like this:

Power is the rate at which energy is transferred.

2) So, the power of a machine is the rate at which it transfers energy. For example, if an electric drill has a power of 700 W, this means it can transfer 700 J of energy every second.
3) This is the very easy formula for power:
4) The proper unit of power is the watt (W). 1 W = 1 J of energy transferred per second (J/s).

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}$$

Example: A motor transfers 4.8 kJ of useful energy in 2 minutes. Find its power output.

1 kJ = 1000 J

$P = W / t = 4800/120 = 40$ W (or 40 J/s)

(Note that the kJ had to be turned into J, and the minutes into seconds.)

4.8 kJ of useful energy transferred in 2 minutes

You've got the power — but watt to do with it...

Make sure you're happy using the equations on this page before you move on.

Q1 An appliance transfers 6 kJ of energy in 30 seconds. Calculate its power. [2 marks]

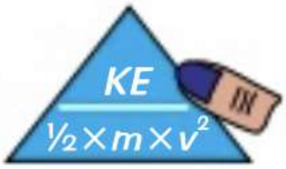
Kinetic and Potential Energy Stores

Now you've got your head around energy stores, it's time to see how you can calculate the amount of energy in two of the most common ones — kinetic and gravitational potential energy stores.

Movement Means Energy in an Object's Kinetic Energy Store

1) Anything that is moving has energy in its kinetic energy store. Energy is transferred to this store when an object speeds up and is transferred away from this store when an object slows down.
2) The energy in the kinetic energy store depends on the object's mass and speed. The greater its mass and the faster it's going, the more energy there will be in its kinetic energy store.
3) There's a slightly tricky formula for it, so you have to concentrate a little bit harder for this one.

Energy in kinetic energy store = ½ × mass × (speed)^2



Example: A car of mass 2450 kg is travelling at 38 m/s. Calculate its kinetic energy.

$KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 2450 \times 38^2 = 1\,768\,900$ J

Raised Objects Store Energy in Gravitational Potential Energy Stores

1) Lifting an object in a gravitational field requires work. This causes a transfer of energy to the gravitational potential energy (g.p.e.) store of the raised object. The higher the object is lifted, the more energy is transferred to this store.
2) The amount of energy in a g.p.e. store depends on the object's mass, its height and the strength of the gravitational field the object is in (p.3).

Energy in gravitational potential energy store = mass × gravitational field strength × height

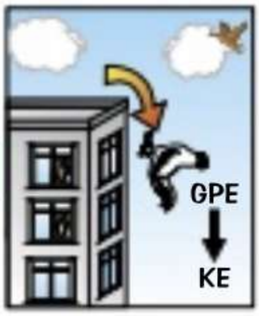
3) You can use this equation to find the change in energy in an object's gravitational potential energy store for a change in height, *h*.

Falling Objects Also Transfer Energy

1) When something falls, energy from its gravitational potential energy store is transferred to its kinetic energy store.
2) For a falling object when there's no air resistance:

Energy lost from the g.p.e. store = Energy gained in the kinetic energy store

3) It's all to do with the Principle of the Conservation of Energy — see page 39.
4) In real life, air resistance (p.4) acts against all falling objects — it causes some energy to be transferred to other energy stores, e.g. the thermal energy stores of the object and surroundings.



Make the most of your potential — jump on your bed...

Wow, that's a lot of energy equations. Make sure you know how to use them all, and remember that the energy in an object's kinetic energy store only changes if it's changing its speed. Now have a crack at this delightful question...

Q1 A 2.0 kg object is dropped from a height of 10 m. Calculate the speed of the object after it has fallen 5.0 m, assuming there is no air resistance. $g = 10$ N/kg. [5 marks]

Non-Renewable Energy and Power Stations

There are different types of energy resources. They fit into two broad types: renewable and non-renewable.

Non-Renewable Energy Resources Will Run Out One Day

The non-renewables are the three FOSSIL FUELS and NUCLEAR:

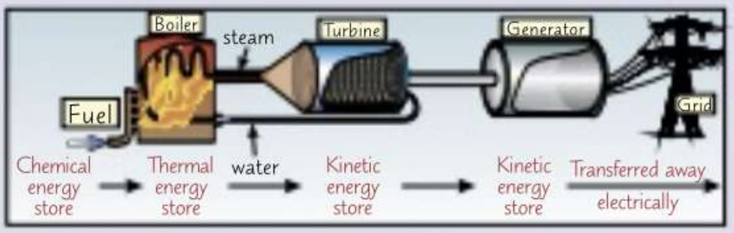
1) Coal
2) Oil
3) Natural gas
4) Nuclear fuels (e.g. uranium and plutonium), see p.49.

a) They will all 'run out' one day.
b) They all do damage to the environment.
c) But they provide most of our energy.

Most Power Stations Use Steam to Drive a Turbine

Most electricity we use is generated from the four NON-RENEWABLE sources of energy (coal, oil, natural gas and nuclear) in big power stations, which are all pretty much the same apart from the boiler (see p.49). Learn the basic features of the typical power station shown here and the energy transfers involved.

1) As the fossil fuel burns (in oxygen) the energy in its chemical energy store is transferred to the thermal energy store of the water by heating.
2) The water boils to form steam, which turns a turbine, transferring energy mechanically to the kinetic energy store of the turbine.



3) As the turbine revolves, so does the generator, which produces an electric current (see page 63). The generator transfers the energy electrically away from the power station, via the national grid.

Fossil Fuels are Linked to Environmental Problems

Burning fossil fuels (oil, natural gas and coal) causes a lot of problems, mainly environmental. But at the moment we still rely on them the most to provide the energy needed to generate electricity.

ADVANTAGES:

1) Burning fossil fuels releases a lot of energy, relatively cheaply.
2) Energy from fossil fuels doesn't rely on the weather, like a lot of renewable energy (see pages 49-51), so it's a reliable energy source.
3) We have lots of fossil fuel power stations already, so we don't need to spend money on new technology to use them.

DISADVANTAGES:

1) All three fossil fuels release carbon dioxide (CO_2) into the atmosphere when burned in power stations. All this CO_2 contributes to global warming and climate change.
2) Burning coal and oil also releases sulfur dioxide (SO_2), which causes acid rain. Acid rain can harm trees and soils and can have a huge impact on wildlife.
3) And a massive disadvantage of using fossil fuels is that THEY'RE EVENTUALLY GOING TO RUN OUT.

Fossil fuels — a coal lotta trouble...

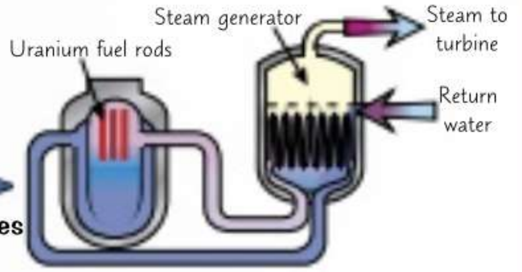
Using fossil fuels can be messy too — "opencast" coal mining leaves loads of soot and sludge all over the landscape, and oil spills can cause serious environmental problems, affecting the wildlife that lives in and around the sea. Not good. But they currently provide most of our energy, so we don't have much choice...

Q1 Describe how a coal-fired power station works. [2 marks]

Nuclear, Wind and Geothermal Power

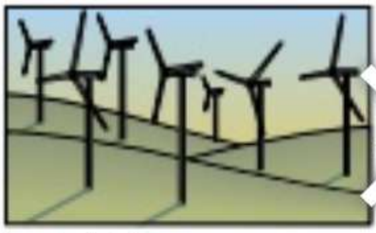
Well, who'd have thought... there's energy lurking about inside atoms, on the breeze and deep underground.

Nuclear Reactors are Just Fancy Boilers



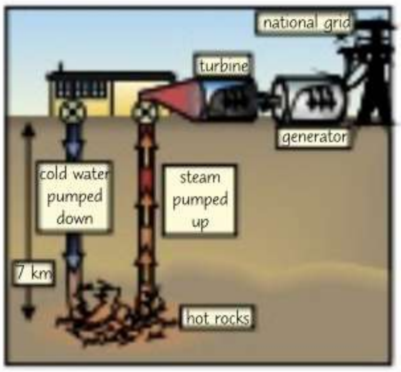
1) A nuclear power station is mostly the same as the one on p. 48. The difference is that nuclear fission (p. 72), e.g. of uranium, produces the heat to make steam to drive turbines etc., rather than burning. So the boiler is a bit different:
2) During the process, energy is transferred from nuclear energy stores to thermal energy stores by heating, then mechanically to kinetic energy stores, and finally transferred electrically through the national grid.
3) Nuclear reactors are expensive to build and maintain, and take longer to start up than fossil fuel ones.
4) Processing the uranium before you use it causes pollution, and there's always a risk of leaks of radioactive material, or even a major catastrophe like at Chernobyl.
5) A big problem with nuclear power is the radioactive waste that you always get.
6) When they're too old and inefficient, nuclear power stations have to be decommissioned (shut down and made safe) — that's expensive too.
7) But there are many advantages to nuclear power. It doesn't produce any of the greenhouse gases which contribute to global warming. Also, there's still plenty of uranium left in the ground (although it can take a lot of money and energy to make it suitable for use in a reactor).

Wind Farms — Lots of Wind Turbines



1) Wind power involves putting lots of wind turbines up in exposed places — like on moors, around the coast or out at sea.
2) Wind turbines use energy from the kinetic energy store of moving air to generate electricity. Wind turns the blades, which turn a generator inside it.
3) Wind turbines are quite cheap to run — they're very tough and reliable, and the wind is free.
4) Wind power doesn't produce any polluting waste and it's renewable — the wind's never going to run out.
5) But there are disadvantages. They spoil the view. You need about 1500 wind turbines to replace one coal-fired power station and 1500 of them cover a lot of ground — which would have a big effect on the scenery. And they can be very noisy, which can be annoying for people living nearby.
6) Another problem is that sometimes the wind isn't strong enough to generate any power. It's also impossible to increase supply when there's extra demand (e.g. when Coronation Street starts).
7) And although the wind is free, it's expensive to set up a wind farm, especially out at sea.

Geothermal Power — Heat from Underground

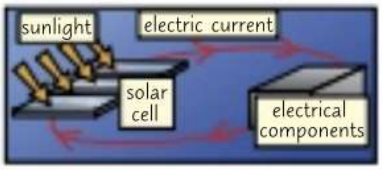


1) This is only possible in certain places where hot rocks lie quite near to the surface. The source of much of the energy is the slow decay of various radioactive elements including uranium deep inside the Earth.
2) Water is pumped in pipes down to the hot rocks and forced back up due to pressure to turn a turbine which drives a generator. So the energy is transferred from thermal energy stores to kinetic energy stores and used to generate electricity.
3) In some places, geothermal energy is used to heat buildings directly.
4) This is actually brilliant, free, renewable energy with no real environmental problems.
5) The main drawback is the cost of drilling down several km.
6) The cost of building a power plant is often high compared to the amount of energy we can get out of it.
7) So there are very few places where this seems to be an economic option (for now).

Solar and Wave Power

Sunshine and waves — a perfect beach holiday AND two sources of renewable energy.

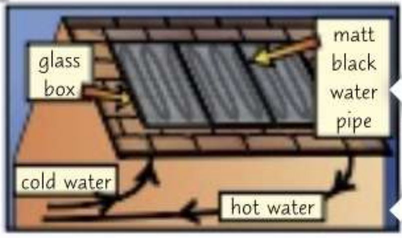
You Can Capture the Sun's Energy Using Solar Cells



1) Solar cells (photocells) use energy from the Sun to directly generate electricity. They generate direct current (d.c.) — the same as a battery (not like the mains electricity in your home, which is a.c. (alternating current) — see p.16).
2) The Sun provides a renewable energy resource — it won't run out (not for 5 billion years anyway).
3) Solar cells are very expensive initially, but after that the energy is free and running costs are almost nil. And there's no pollution produced while using them (although some is produced during their manufacture).
4) They're usually used to generate electricity on a relatively small scale, e.g. powering individual homes.
5) It's often too expensive or not practical to connect them to the national grid — the cost of connecting them to the national grid can be enormous compared with the value of the electricity generated.
   Solar cells can only generate enough electricity to be useful if they have enough sunlight — which can be a problem at night (and in winter in some places). But the cells can be linked to rechargeable batteries to create a system that can store energy during the day for use at night.
6) Solar cells are often the best way to power calculators or watches that don't use much energy. They're also used in remote places where there's not much choice (e.g. deserts) and in satellites.

Solar Heating Systems — No Complex Mechanical Stuff

SOLAR WATER HEATING PANELS

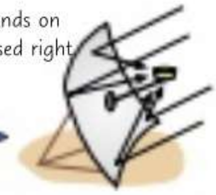


Solar water heating panels are more simple than solar cells — they're basically just black water pipes inside a glass box. The glass lets energy from the Sun in, which is then absorbed by the black pipes and heats up the water.

Like solar cells, they cost money to set up, but are renewable and free after that. They're only used for small-scale energy production.

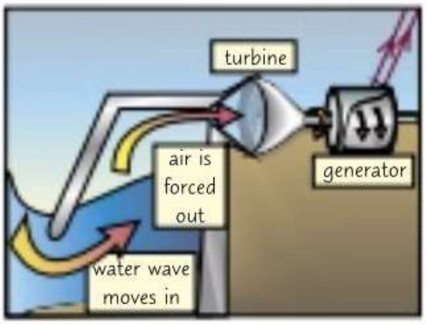
COOKING WITH SOLAR POWER

If you get a curved mirror, then you can focus the Sun's light. This is what happens in a solar oven. They provide a renewable energy resource for outdoor cooking. But they're slow, bulky and unreliable — they need strong sunlight to work.



All the radiation that lands on the curved mirror is focused right on your pan.

Wave Power — Lots of Little Wave Converters



1) One way of harvesting wave power is with lots of small wave converters located around the coast. As waves come in to the shore they provide an up and down motion which can be used to drive a generator.
2) The energy is transferred from the kinetic energy store of the waves to the kinetic energy store of the turbine, and used to generate electricity.
3) There's no pollution and it's renewable.
4) The main problems are spoiling the view and being a hazard to boats.
5) It's fairly unreliable, since waves tend to die out when the wind drops.
6) Initial costs are high but there are no fuel costs and minimal running costs.
   Wave power is unlikely to provide energy on a large scale but it can be very useful on small islands.

Learn about wave power — and bid your cares goodbye...

Two great small-scale renewable energy resources here — they're both dependent on the weather though.

Q1 Give one negative impact of generating electricity using wind turbines. [1 mark]

Q2 Give one advantage and one disadvantage of generating electricity using solar power. [2 marks]

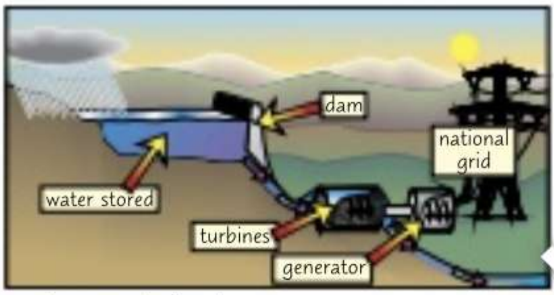
Generating Electricity Using Water

Water, water, everywhere. Perfect for generating electricity.

Tidal Barrages Generate Energy When the Tide Goes In and Out

1) Tidal barrages are big dams built across river estuaries, with turbines in them. As the tide comes in it fills up the estuary to a height of several metres. This water can then be allowed out through turbines at a controlled speed. It also drives the turbines on the way in.
2) The energy is transferred from the kinetic energy stores of the water to the kinetic energy store of the turbine, and used to generate electricity.
3) There's no pollution and it's renewable. The main problems are preventing free access by boats, spoiling the view and altering the habitat of the wildlife.
4) Tides are pretty reliable, but the height of the tide is variable so lower tides will provide less energy than higher ones.
5) Initial costs are moderately high, but there's no fuel costs and minimal running costs.

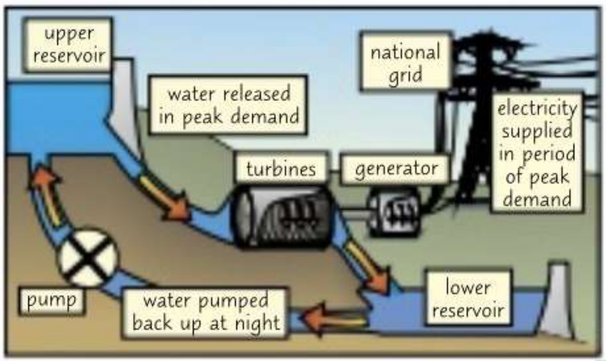
Hydroelectricity — Catching Rainwater



1) Hydroelectric power often requires the flooding of a valley by building a big dam. Rainwater is caught and allowed out through turbines, transferring energy from the gravitational potential energy store of the water to kinetic energy stores as it falls, which is used to generate electricity.
2) It's a renewable energy resource.
3) There is no pollution (as such), but there's a big impact on the environment due to flooding the valley (rotting vegetation releases methane and CO_2) and possible loss of habitat for some species. The reservoirs can also look very unsightly when they dry up. Location in remote valleys can avoid some of these problems.
4) A big advantage is immediate response to increased demand. If more energy is needed than the national grid can supply, the water's released. There's no problem with reliability except in times of drought.
5) Initial costs are high, but there's no fuel and low running costs.

Pumped Storage Gives Extra Supply Just When it's Needed

1) Most large power stations have huge boilers which have to be kept running all night even though demand is very low. This means there's a surplus of electricity at night — and it's surprisingly difficult to find a way of keeping this spare energy for later use. Pumped storage is one of the best solutions.
2) In pumped storage, 'spare' night-time electricity is used to pump water up to a higher reservoir.
3) This can then be released quickly during periods of peak demand, such as at teatime each evening, to supplement the steady delivery from the big power stations.
4) The 'spare' electricity is used to transfer energy back to the water's gravitational potential energy stores, so that it may generate more electricity when it is needed by flowing through the dam.



The hydroelectric power you're supplying — it's electrifying...

Some other parts of the world rely heavily on hydroelectric power for their electricity. For example, in the last few years, 99% of Norway's energy came from hydroelectric power. 99% — that's huge!

Q1 Give one advantage and one disadvantage of producing hydroelectricity. [2 marks]

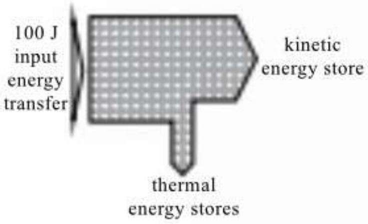
Revision Questions for Section 4

Phew... what a relief, you've made it to the end of yet another nice long section. This one's been fairly straightforward but there are a shedload of facts to remember and you need to know the lot of them. And the best way to check that you know them all is...

- Try these questions and tick off each one when you get it right.
- When you've done all the questions for a topic and are completely happy with it, tick off the topic.

Energy Transfers and Efficiency (p.39-42) ☐

1) Name eight types of energy store. ☐
2) State the principle of the conservation of energy. ☐
3) What is the efficiency of a motor that has an input energy transfer of 120 J and transfers 90 J usefully to the motor's kinetic energy store? ☐
4) Describe the energy transfers that occur in a battery-powered toy car. ☐
5) The following Sankey diagram shows how energy is converted in a catapult.



a) How much energy is converted into kinetic energy?
b) How much energy is wasted?
c) What is the efficiency of the catapult? ☐

Energy Transfers by Heating (p.43-45) ☐

6) Describe the three ways that energy can be transferred by heating. ☐
7) Describe how the energy is transferred from a heating element throughout the water in a kettle. What is this process called? ☐
8) Describe how insulation reduces energy transfers. ☐

Calculating Energy and Power (p.46-47) ☐

9) What's the formula for work done? A dog drags a big branch 12 m over the next-door neighbour's front lawn, pulling with a force of 535 N. How much work was done? ☐
10) An electric motor uses 540 kJ of electrical energy in 4.5 minutes. What is its power consumption? ☐
11) Write down the formula for the energy in an object's kinetic energy store. Find the energy in the kinetic energy store of a 78 kg sheep moving at 2.3 m/s. ☐
12) What happens to the amount of energy in an object's gravitational potential energy store when it is lifted above the ground? ☐
13) Write down the formula for the energy in an object's gravitational potential energy store. Find the energy in the g.p.e. store of a 78 kg sheep on top of a 2 m ladder (use $g = 10\ \text{m/s}^2$). ☐

Energy Resources (p.48-51) ☐

14) a) Describe the energy transfers that take place when burning fossil fuels to generate electricity in a typical power station.
    b) How does this differ in a nuclear power station? ☐
15) State two advantages and two disadvantages of using fossil fuels to generate electricity. ☐
16) Outline two arguments for and two arguments against increasing the use, in the UK, of nuclear power. ☐
17) Describe the energy transfers that take place when the following renewable resources and methods are used to generate electricity:
    a) geothermal energy b) waves c) the tide ☐
18) State one advantage and one disadvantage for each resource or method in question 17. ☐

Density and Pressure

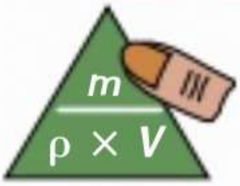
You might find this stuff a bit tricky — but just read it through carefully and take the pressure off.

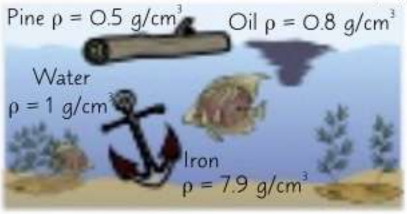
Density is Mass per Unit Volume

The symbol for density is a Greek letter rho (ρ) — it looks like a p but it isn't.

Density is a measure of the 'compactness' (for want of a better word) of a substance. It relates the mass of a substance to how much space it takes up.

$$\text{Density } (\rho) = \frac{\text{mass } (m)}{\text{volume } (v)}$$





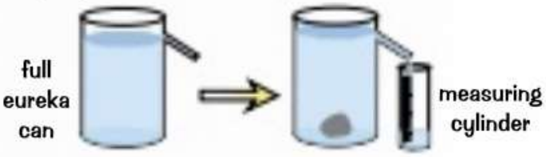
The units of density are g/cm³ or kg/m³
N.B. 1 g/cm³ = 1000 kg/m³

1) The density of an object depends on what it's made of. Density doesn't vary with size or shape.
2) The average density of an object determines whether it floats or sinks — a solid object will float on a fluid if it has a lower density than the fluid.

You Can Find the Density of an Object from its Mass and Volume

PRACTICAL

1) To measure the density of a substance, use a balance to measure its mass.
2) If it's a box shape, start by measuring its length, width and height with an appropriate piece of equipment (e.g. a ruler). Then calculate its volume by multiplying the length, width and height together.
3) For an irregular solid, you can find its volume by submerging it in a eureka can filled with water. The water displaced by the object will be transferred to the measuring cylinder.
4) Record the volume of water in the measuring cylinder. This is also the volume of the object.
5) Plug the object's mass and volume into the formula above to find its density.



Pressure is Force per Unit Area

1 kPa = 1000 Pa

Pressure is a measure of the force being applied to the surface of something. It relates how much force is being applied to an object (in N) to the area that it is applied over (in m²). Pressure is measured in pascals (Pa) or kilopascals (kPa). 1 pascal is defined as 1 N/m².

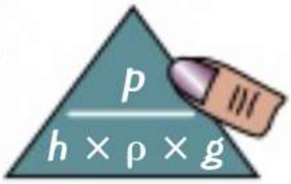
$$\text{Pressure} = \frac{\text{force}}{\text{area}}$$

The symbol for pressure is a p — don't confuse it with density (ρ).

1) The same force applied over a larger area creates a lower pressure.
2) In gases and liquids at rest, the pressure at any point acts equally in all directions.
3) In gases and liquids, the pressure increases with depth. The pressure is higher at the bottom of the sea than at the surface, and it is lower high up in the atmosphere than close to the Earth.

Pressure Difference in Liquids and Gases Depends on Density

Pressure difference is the difference in pressure between two points in a liquid or gas. It depends on the height difference (in m), and the density (in kg/m³) of the substance. Gravity has an effect too — g is the gravitational field strength, which is around 10 m/s².



$$\text{Pressure difference} = \text{height} \times \text{density} \times \text{gravitational field strength}$$

Pressure — pushing down on me...

Remember — density is all about how tightly packed the particles in a substance are. Nice and simple really.

Q1 An object has a mass of 0.45 kg and a volume of 75 cm³. Calculate its density in kg/m³. [3 marks]

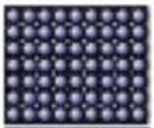
Q2 A vase with a base area of 0.044 m² applies 49 N to a table surface. Calculate the pressure on the table. [1 mark]

Changes of State

Solid → melts → Liquid → boils → Gas → condenses → Liquid → solidifies → Solid. Easy peasy.

Kinetic Theory Can Explain the Three States of Matter

1) The three states of matter are solid (e.g. ice), liquid (e.g. water) and gas (e.g. water vapour). The particles of a substance in each state are the same — only the arrangement and energy of the particles are different.



SOLIDS — strong forces of attraction hold the particles close together in a fixed, regular arrangement. The particles don't have much energy so they can only vibrate about their fixed positions.

LIQUIDS — there are weaker forces of attraction between the particles. The particles are close together, but can move past each other, and form irregular arrangements. They have more energy than the particles in a solid — they move in random directions at low speeds.

GASES — There are almost no forces of attraction between the particles. The particles have more energy than those in liquids and solids — they are free to move, and travel in random directions and at high speeds.

2) The energy in a substance's thermal energy store is held by its particles in their kinetic energy stores — this is what the thermal energy store actually is.

3) When you heat a liquid, the extra energy is transferred into the particles' kinetic energy stores, making them move faster. Eventually, when enough of the particles have enough energy to overcome their attraction to each other, big bubbles of gas form in the liquid — this is boiling.

The melting point of a substance is the temperature at which it turns from a solid to a liquid.
The boiling point is the temperature at which a liquid becomes a gas.

4) It's similar when you heat a solid. The extra energy makes the particles vibrate faster until eventually the forces between them are partly overcome and the particles start to move around — this is melting.

5) When a substance is melting or boiling, you're still putting in energy, but the energy's used for breaking bonds between particles rather than raising the temperature. So the substance stays at a constant temperature.

6) When a substance is condensing or freezing, bonds are forming between particles, which releases energy. This means the temperature doesn't go down until all of the substance has changed state.

Evaporation is a Special Example of Changing States

1) Evaporation is when particles escape from a liquid and become gas particles.

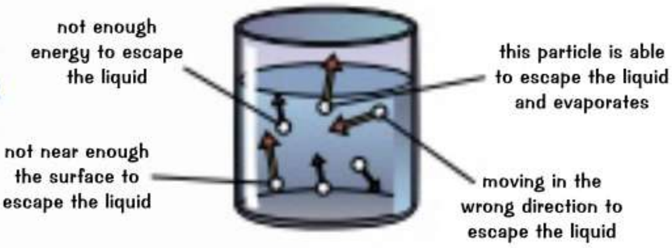
2) Particles can evaporate from a liquid at temperatures that are much lower than the liquid's boiling point.

3) Particles near the surface of a liquid can escape and become gas particles if:

- The particles are travelling in the right direction to escape the liquid.
- The particles are travelling fast enough (they have enough energy in their kinetic energy stores) to overcome the attractive forces of the other particles in the liquid.

4) The fastest particles (with the most energy) are most likely to evaporate from the liquid — so when they do, the average speed and energy in the kinetic energy stores of the remaining particles decreases.

5) This decrease in average particle energy means the temperature of the remaining liquid falls — the liquid cools.



6) This cooling effect can be really useful. For example, you sweat when you exercise or get hot. As the water from the sweat on your skin evaporates, it cools you down.

All this talk of kinetic theory has left me in a right state...

Unfortunately not a page about American state history. Sorry about that — it would have been a fun page (ish), but I might've got in trouble and you would've ended up snookered if any of this came up in the exam.

Q1 Explain how particles are able to escape a liquid before it reaches its boiling point. [2 marks]

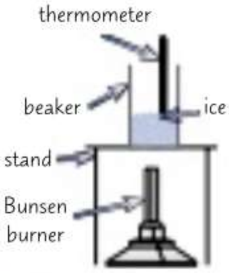
Temperature and Particle Theory

Temperature-time graphs, particles in gases, and absolute zero — ooh, sounds like fun...

You Can Obtain a Temperature-Time Graph for Water

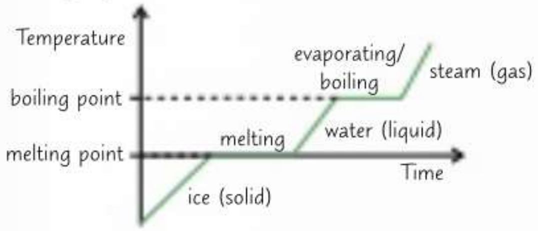
PRACTICAL

You can do a simple experiment to show that temperature remains constant during changes of state:

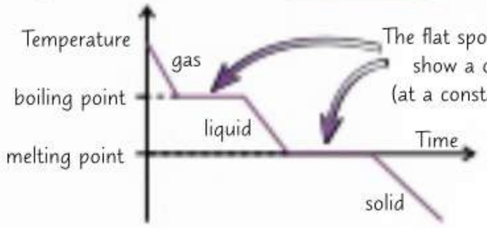


1) Fill a beaker with crushed ice. Place a thermometer into the beaker and record the temperature of the ice.
2) Using the Bunsen burner, gradually heat the beaker full of ice.
3) Every twenty seconds, record the temperature and the current state of the ice (e.g. partially melted, completely melted). Continue this until the water begins to boil.
4) Plot a graph of temperature against time for your experiment.

Your graph should look like this:



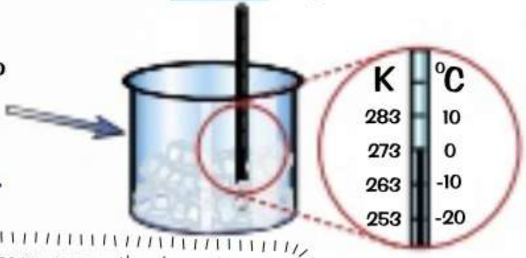
You get a similar one for condensing and freezing:



The flat spots on both graphs show a change of state (at a constant temperature).

Absolute Zero is as Cold as Stuff Can Get — 0 Kelvins

1) If you increase the temperature of something, you give its particles more energy — they move about more quickly or vibrate more. Similarly, if you cool a substance down, you reduce the energy of the particles.
2) The coldest that anything can ever get is –273 °C — this temperature is known as absolute zero. At absolute zero, the particles have as little energy in their kinetic stores as it's possible to get.
3) Absolute zero is the start of the Kelvin scale of temperature.
4) A temperature change of 1 °C is also a change of 1 kelvin. The two scales are similar — the only difference is where the zero occurs.
5) To convert from degrees Celsius to kelvins, just add 273. And to convert from kelvins to degrees Celsius, just subtract 273.



	Absolute zero	Freezing point of water	Boiling point of water
Celsius scale	–273 °C	0 °C	100 °C
Kelvin scale	0 K	273 K	373 K

For some reason, there's no degree symbol ° when you write a temperature in kelvins. Just write K, not °K. OK.

Energy in Particles' Kinetic Energy Stores is Proportional to Temperature

1) Particle theory says that gases consist of very small particles which are constantly moving in completely random directions. The particles hardly take up any space — most of the gas is empty space.
2) The particles constantly collide with and bounce off of each other and the container walls.
3) If you increase the temperature of a gas, you give its particles more energy. If you double the temperature (measured in kelvins), you double the average energy in the kinetic energy stores of the particles.

The temperature of a gas (in kelvins) is proportional to the average energy in the kinetic energy stores of its particles.

4) As you heat up a gas, the average speed of its particles increases. Anything that's moving has energy in its kinetic energy store. This energy is equal to $\frac{1}{2}mv^2$, remember (see p.47).

Absolute zero — nought, zilch, not a sausage...

Nothing can be colder than zero kelvins (or –273 °C) — at this temperature, particles are pretty much still.

Q1 Find the value of 25 °C in kelvins. [1 mark]

Particle Theory and Pressure in Gases

The pressure of a gas is explained by the movement of its particles. Fascinating stuff... Well, almost.

Particle Theory Says Colliding Gas Particles Create Pressure

1) As gas particles move about, they randomly bang into each other and whatever else gets in the way.
2) Gas particles are very light, but they sure ain't massless. When they collide with something, they exert a force on it and their momentum and direction change. In a sealed container, gas particles smash against the container's walls — creating an outward pressure.
3) This pressure depends on how fast the particles are going and how often they hit the walls.
4) If you heat a gas, the particles move faster and have more energy in their kinetic stores. This increase in energy means the particles hit the container walls harder and more frequently, resulting in a larger force, creating more pressure. In fact, temperature (in K) and pressure are proportional — double the temperature of a fixed amount of gas, and you double the pressure.
5) And if you put the same fixed amount of gas in a bigger container, the pressure will decrease, cos there'll be fewer collisions between the gas particles and the container's walls. When the volume's reduced, the particles get more squashed up and so they hit the walls more frequently, producing a larger force over a smaller surface area, which increases the pressure.

At Constant Temperature "pV = Constant"

This all applies to so-called ideal gases. Ideal gases are gases that are 'well behaved', i.e. ones that this equation works for... Scientists, eh.

Learn this equation:

For a fixed mass of gas at a constant temperature:

$$\text{pressure} \times \text{volume} = \text{constant} \rightarrow pV = \text{constant}$$

You can also write the equation as $p_1V_1 = p_2V_2$

(where p_1 and V_1 are your starting conditions and p_2 and V_2 are your final conditions).

Writing it like that is much more useful a lot of the time.

EXAMPLE: A gas at a pressure of 250 kilopascals is compressed from a volume of 300 cm³ down to a volume of 175 cm³. The temperature of the gas does not change. Find the new pressure of the gas, in kilopascals.

$p_1V_1 = p_2V_2$ gives: $250 \times 300 = p_2 \times 175$, so $p_2 = (250 \times 300) \div 175 = 429$ kPa (3 s.f.).

At Constant Volume "p/T = Constant"

Learn this equation too:

In a sealed container (i.e. constant volume):

$$\frac{\text{pressure}}{\text{temperature (in K)}} = \text{constant} \rightarrow \frac{p}{T} = \text{constant}$$

You can also write the equation as $p_1/T_1 = p_2/T_2$

(where p_1 and T_1 are your starting conditions and p_2 and T_2 are your final conditions).

EXAMPLE: A container has a volume of 30 litres. It is filled with gas at a pressure of 100 kPa and a temperature of 290 K. Find the new pressure if the temperature is increased to 315 K.

$p_1/T_1 = p_2/T_2$ gives: $100 \div 290 = p_2 \div 315$ so $p_2 = 315 \times (100 \div 290) = 109$ kPa (3 s.f.).

NB: The temperatures in this formula must always be in kelvins, so if they give you the temperatures in °C, convert to kelvins FIRST (by adding 273). Always keep the pressure units the same as they are in the question (in this case, kPa).

Less space, more collisions, more pressure — just like London...

The nice thing is that you don't need to fully understand the physics — you just need a bit of "common sense" about formulas. Understanding always helps of course, but you can still get the right answer without it.

Q1 An ideal gas held at a pressure of 310 kPa is compressed to a third of its original volume. Calculate the new pressure of the gas. [3 marks]

Specific Heat Capacity

The temperature of something isn't quite the same thing as the energy stored in the substance's thermal energy store. That's where specific heat capacity comes in...

Specific Heat Capacity Relates *Temperature* and *Energy*

1) Heating a substance increases the energy in its thermal energy store. You may see this referred to as the internal energy of a substance.
2) So temperature is a way of measuring the average internal energy of a substance.
3) However, it takes more energy to increase the temperature of some materials than others. E.g. you need 4200 J to warm 1 kg of water by 1 °C, but only 139 J to warm 1 kg of mercury by 1 °C.
4) Materials that need to gain lots of energy to warm up also release loads of energy when they cool down again. They store a lot of energy for a given change in temperature.
5) The change in the energy stored in a substance when you heat it is related to the change in its temperature by its specific heat capacity. The specific heat capacity of a substance is the energy required to change the temperature of an object by 1 °C per kilogram of mass. E.g. water has a specific heat capacity of 4200 J/kg°C (that's pretty high).
6) You need to know how to use the equation relating energy, mass, specific heat capacity and temperature.

$$\Delta Q = m \times c \times \Delta T$$

Change in thermal energy (J)

Mass (kg)

Specific heat capacity (J/kg°C)

Change in temperature (°C)

Δ just means 'change in'.

You can Find the Specific Heat Capacity of Water

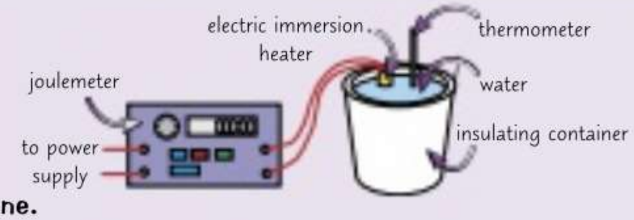
PRACTICAL

You can use the experiment below to find the specific heat capacity of water — or any liquid for that matter.

If you can, you should use a thermally insulated container for both of these experiments to reduce energy wasted to the surroundings (p.45).

You could also use a voltmeter and ammeter instead of a joulemeter. Time how long the heater was on for, then calculate the energy supplied using $E = VIt$ (p.22).

1) Use a mass balance to measure the mass of the insulating container.
2) Fill the container with water and measure the mass again. The difference in mass is the mass of the water in the container.
3) Set up the experiment as shown — make sure the joulemeter reads zero and place a lid on the container if you have one.



4) Measure the temperature of the water, then turn on the power.
5) Keep an eye on the thermometer. When the temperature has increased by e.g. ten degrees, switch off the power and record this temperature increase and the energy on the joulemeter.
6) You can then calculate the specific heat capacity of the water by rearranging the equation above, and plugging in your measurements.
7) Repeat the whole experiment at least three times, then calculate an average of the specific heat capacity.

Your experimental value for the specific heat capacity will probably be a bit too high, since some of the heat supplied will be lost to the environment.

You can use a similar method to find the specific heat capacity of a solid. Make sure the block of material you use has two holes in it for the heater and thermometer, and wrap it up with an insulating layer before starting. When you have switched off the power and finished timing, wait until the temperature has stopped increasing before recording the highest final temperature — this gives the energy from the heater time to spread through the solid block.

I wish I had a high specific fact capacity...

Make sure you practise using that equation — it's a bit of a tricky one.

Q1 If a metal has a specific heat capacity of 420 J/kg°C, calculate how much the temperature of a 0.20 kg block of the metal will increase by if 1680 J of energy are supplied to it. [2 marks]

Revision Questions for Section 5

Lots of maths and formulae in this section. You have learnt them, haven't you? Well, there's only one way to know...

- Try these questions and tick off each one when you get it right.
- When you've done all the questions for a topic and are completely happy with it, tick off the topic.

Density and Pressure (p.53) ☐

1) What is the relationship between the density, mass and volume of a substance? ☐
2) Calculate the volume of 2 kg of water (density = 1000 kg/m^3). ☐
3) How would you measure the density of an unknown cube of material in the lab? ☐
4) Draw a formula triangle containing pressure, force and area. ☐
5) What pressure does a woman weighing 600 N exert on the floor if her high-heeled shoes have an area of 5 cm^2 touching the floor? ☐
6) What is the formula used to work out a pressure difference in liquids and gases? ☐

Changes of State (p.54) ☐

7) Describe how the particles are arranged and move in:
   a) a solid, b) a liquid, c) a gas. ☐
8) Explain what happens to particles in a substance during:
   a) melting, b) boiling, c) evaporation. ☐
9) A substance is heated, and its temperature rises until it melts from a solid to a liquid. The substance then rises in temperature again until it begins to boil. Sketch a temperature-time graph to show this. ☐

Temperature and Pressure in Gases (p.55-56) ☐

10) What temperature is 'absolute zero' in
    a) kelvins, b) degrees Celsius? ☐
11) How does the temperature of a gas (in kelvins) relate to the energy in the kinetic stores of its particles? ☐
12) Explain why the molecules in a gas exert a pressure on the walls of a container. ☐
13) What happens to the pressure of a gas in a sealed container if you increase the temperature? ☐
14) 500 cm^3 of a fixed mass of gas at 50 kPa is forced into a 100 cm^3 container. What is the new pressure of the gas (assuming the temperature is kept constant)? ☐
15) Another 500 cm^3 of gas is kept sealed in its container at 50 kPa, but is then heated from a temperature of 290 K to 300 K. What is the new pressure of the gas? ☐

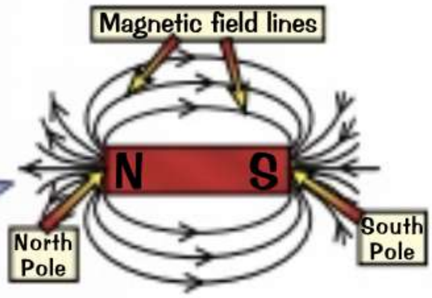
Specific Heat Capacity (p.57) ☐

16) What equation relates energy, mass, specific heat capacity and temperature? ☐
17) 110 J of energy is supplied to a substance to heat it from a temperature of 21 °C to 45 °C. The substance has a mass of 0.25 kg. Calculate the specific heat capacity of the substance. ☐
18) Describe an experiment that can be used to find the specific heat capacity of a solid. ☐

Magnets and Magnetic Fields

I think magnetism is an attractive subject, but don't get repelled by the exam — revise.

Magnets Produce Magnetic Fields



1) All magnets have two poles — north and south.
2) A magnetic field is a region where magnetic materials (e.g. iron) experience a force.
3) Magnetic field lines (or "lines of force") are used to show the size and direction of magnetic fields. They always point from NORTH to SOUTH.
4) Placing the north and south poles of two permanent bar magnets near each other creates a uniform field between the two magnets.

Magnetic Field Patterns can be Seen Using Compasses

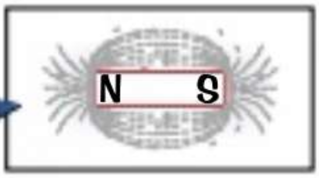
PRACTICAL

1) Compasses and iron filings align themselves with magnetic fields.
2) You can use multiple compasses to see the magnetic field lines coming out of a bar magnet or between two bar magnets.

You shouldn't put the compasses too close to each other. Compasses also produce magnetic fields — you need to make sure you're measuring the field of the magnet rather than the compasses nearby.

If you don't have lots of compasses, you can just use one and move it around (trace its position on some paper before each move if it helps).

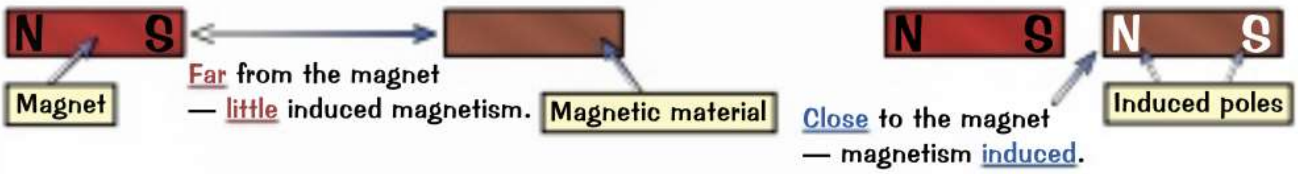
3) You could also use iron filings to see magnetic field patterns. Just put the magnet(s) under a piece of paper, scatter the iron filings on top, and tap the paper until the iron filings form a clear pattern.



Magnetism can be Induced

1) Magnets affect magnetic materials and other magnets.
2) Like poles repel each other and opposite poles attract.

3) Both poles attract magnetic materials (that aren't magnets).
4) When magnetic materials are brought near to a magnet (into its magnetic field), that material acts as a magnet.
5) This magnetism has been induced by the original magnet.
6) The closer the magnet and the magnetic material get, the stronger the induced magnetism will be.



Magnets are like farmers — surrounded by fields...

Loads of really useful things work because of magnetism — compasses, headphones, computer hard drives, MRI medical scanners, mass spectrometers, those little magnets that hold your fridge door closed...

Q1 Sketch the magnetic field pattern between two magnets that are lined up next to each other with their south poles close together. [2 marks]

Electromagnetism

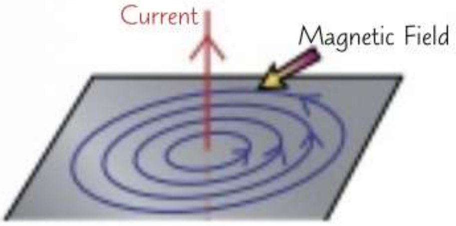
Permanent magnets are great, but it would be really handy to be able to turn a magnetic field on and off. Well, it turns out that when electric current flows it produces a magnetic field — problem solved. Hooray.

A Current-Carrying Wire Creates a Magnetic Field

1) An electric current in a conductor produces a magnetic field around it.
2) The larger the electric current, the stronger the magnetic field.
3) The direction of the magnetic field depends on the direction of the current.

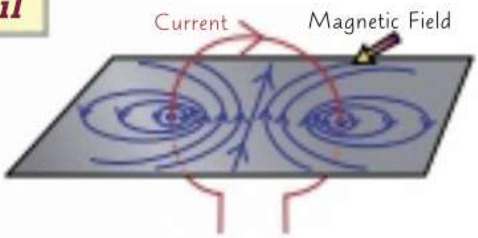
The Magnetic Field Around a Straight Wire

1) There is a magnetic field around a straight, current-carrying wire.
2) The field is made up of concentric circles with the wire in the centre.

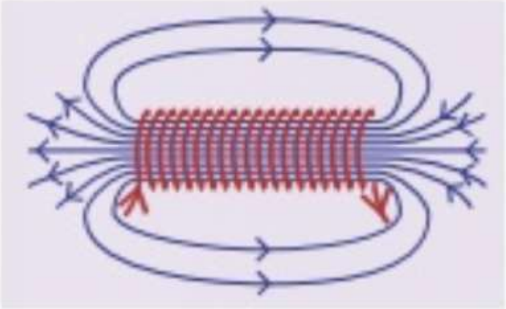


The Magnetic Field Around a Flat Circular Coil

1) The magnetic field in the centre of a flat circular coil of wire is similar to that of a bar magnet.
2) There are concentric ellipses (stretched circles) of magnetic field lines around the coil.



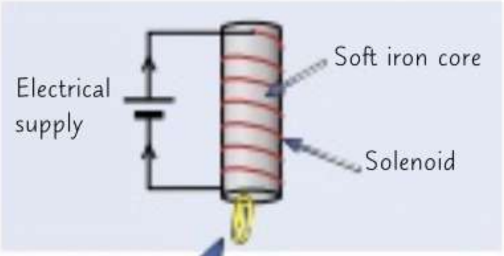
The Magnetic Field Around a Solenoid



1) The magnetic field inside a current-carrying solenoid (a coil of wire) is strong and uniform.
2) Outside the coil, the field is just like the one around a bar magnet.
3) This means that the ends of a solenoid act like the north pole and south pole of a bar magnet.
This type of magnet is called an ELECTROMAGNET.

Magnetic Materials can be 'Soft' or 'Hard'

1) A magnetic material is considered 'soft' if it loses its induced magnetism quickly, or 'hard' if it keeps it permanently.
2) Iron is an example of a soft magnetic material.
Steel is an example of a hard magnetic material.
3) Iron is used in transformers because of this property — it needs to magnetise and demagnetise 50 times a second (mains electricity in the UK runs at 50 Hz) — see p.64.
4) You can increase the strength of the magnetic field around a solenoid by adding a magnetically "soft" iron core through the middle of the coil.



A soft iron bar walks into a solenoid...

...and suddenly has a magnetic personality. Groan. Enough of the bad jokes — electromagnetism allows us to make electric motors, doorbells, those giant magnets that pick up cars in scrapyards, magnetic locks, particle accelerators, levitating trains... Frogs can even be made to float in mid-air. Fact.

Q1 Explain the difference between 'soft' and 'hard' magnetic materials. [2 marks]

The Motor Effect

The motor effect can happen when you put a current-carrying wire in a magnetic field. It's really useful in stuff like... well... electric motors. If you want to know exactly what it is, you'll have to keep reading.

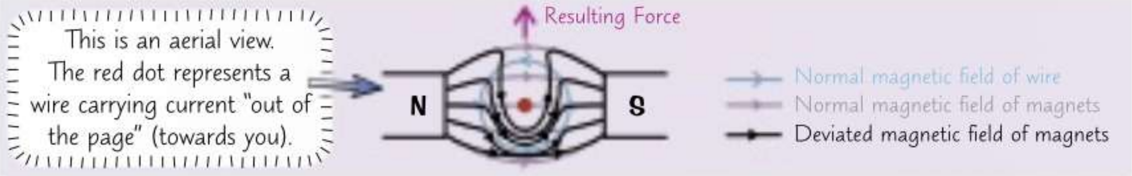
A Current in a Magnetic Field Experiences a Force

Paper 2

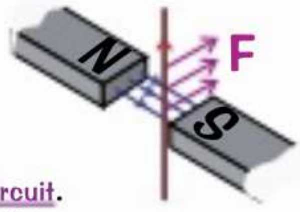
Paper 2

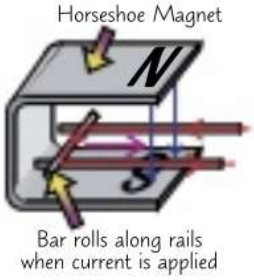
When a current-carrying wire is put between magnetic poles, the two magnetic fields affect one another. The result is a force on the wire. This can cause the wire to move. This is called the motor effect.

This is because charged particles (e.g. electrons in a current) moving through a magnetic field will experience a force, as long as they're not moving parallel to the field lines.


This is an aerial view. The red dot represents a wire carrying current "out of the page" (towards you).

1) To experience the full force, the wire has to be at 90° to the magnetic field. If the wire runs along the magnetic field, it won't experience any force at all. At angles in between, it'll feel some force.
2) The force always acts in the same direction relative to the magnetic field of the magnets and the direction of the current in the wire.
3) A good way of showing the direction of the force is to apply a current to a set of rails inside a horseshoe magnet (shown opposite). A bar is placed on the rails, which completes the circuit. This generates a force that rolls the bar along the rails.



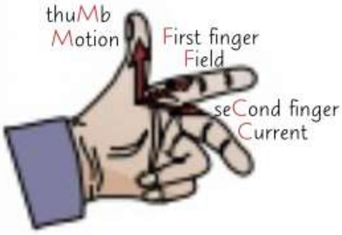


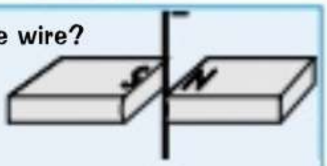
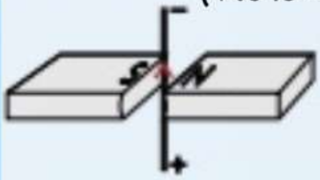
Bar rolls along rails when current is applied

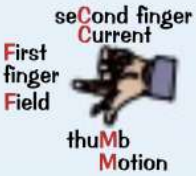
4) The magnitude (strength) of the force increases with the strength of the magnetic field.
5) The force also increases with the amount of current passing through the conductor.
6) Reversing the current or the magnetic field also reverses the direction of the force.

Fleming's Left-Hand Rule Tells You Which Way the Force Acts

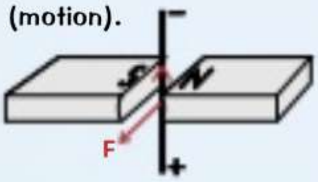
1) They could test if you can do this, so practise it.
2) Using your left hand, point your First finger in the direction of the Field and your seCond finger in the direction of the Current.
3) Your thuMb will then point in the direction of the force (Motion).



EXAMPLE: Which direction is the force on the wire?

ANSWER: 1) Draw in current arrows (+ve to –ve).

2) Fleming's LHR.



3) Draw in direction of force (motion).



Remember the Left-Hand Rule for the motor effect — drive on the left...

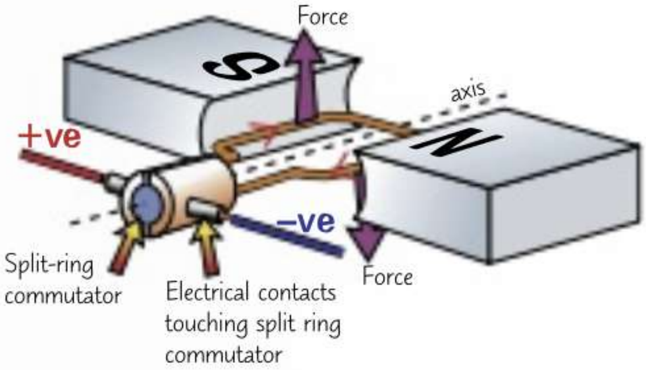
You're going to need to know the difference between left and right for this page. Learn the rule and use it — don't be scared of looking like a muppet in the exam. Learn all the details, diagrams and all, then cover the page and scribble it all down from memory. Then check back, see what you've missed, and try again.

Q1 State what the three fingers in Fleming's Left-Hand Rule represent. [1 mark]

Electric Motors and Loudspeakers

Aha — one of the favourite exam topics of all time. Read it. Understand it. Learn it.

A Simple D.C. Electric Motor



4 Factors which Speed it up

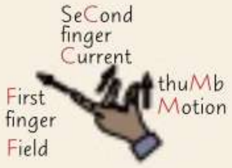
1) More current
2) More turns on the coil
3) Stronger magnetic field
4) A soft iron core in the coil

1) The diagram shows the forces acting on the two side arms of the coil.
2) These forces are just the usual forces which act on any current in a magnetic field.
3) Because the coil is on a spindle and the forces act one up and one down, it rotates.
4) The split-ring commutator is a clever way of swapping the contacts every half turn to keep the motor rotating in the same direction.
5) The direction of the motor can be reversed either by swapping the polarity of the d.c. supply or swapping the magnetic poles over.
6) The speed can be increased by adding more turns to the coil, increasing the current, increasing the strength of the magnetic field or by adding a soft iron core.
7) You can use Fleming's left-hand rule to work out which way the coil will turn.

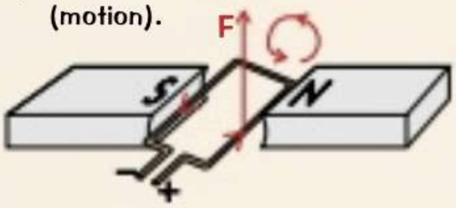
EXAMPLE: Is the coil turning clockwise or anticlockwise?

ANSWER: 1) Draw in current arrows (+ve to –ve).

2) Fleming's LHR on one arm (I've used the right-hand arm).



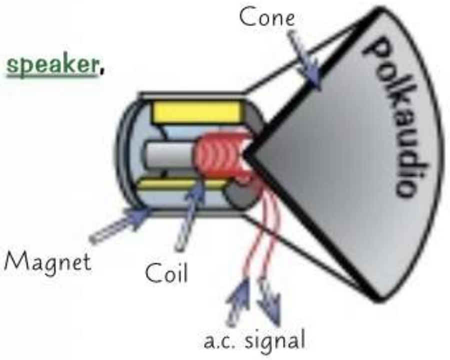
3) Draw in direction of force (motion).



So — the coil is turning anticlockwise.

Loudspeakers Work Because of the Motor Effect

1) A.c. electrical signals from an amplifier are fed to a coil of wire in the speaker, which is wrapped around the base of a cone.
2) The coil is surrounded by a permanent magnet, so the a.c. signals cause a force on the coil and make it move back and forth.
3) These movements make the cone vibrate and this creates sounds.



If a loudspeaker falls in the forest does it still make a sound...

Next time you're walking along listening to music think of the enjoyment that the motor effect is bringing you. Physics can make you happy. Keep going with the revision — good exam results can make you happy too.

Q1 State two ways to reverse the direction of rotation of a simple d.c. electric motor. [2 marks]

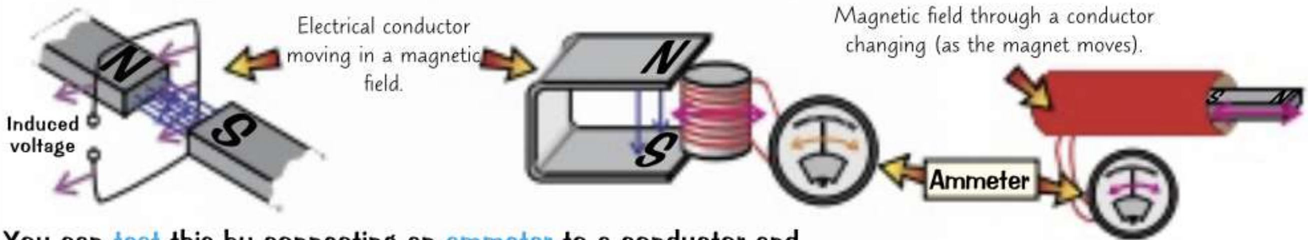
Electromagnetic Induction

Generators use a pretty cool piece of physics to make electricity from the movement of a turbine. It's called electromagnetic (EM) induction — which basically means making electricity using a magnet.

ELECTROMAGNETIC INDUCTION: The creation of a VOLTAGE (and maybe current) in a wire which is experiencing a CHANGE IN MAGNETIC FIELD.

The Dynamo Effect — Move the Wire or the Magnet

1) Using electromagnetic induction to generate electricity using energy from kinetic energy stores is called the dynamo effect. (In a power station, this energy is provided by the turbine.)
2) There are two different situations where you get EM induction:
    a) An electrical conductor (a coil of wire is often used) moves through a magnetic field.
    b) The magnetic field through an electrical conductor changes (gets bigger or smaller or reverses).



Electrical conductor moving in a magnetic field.

Magnetic field through a conductor changing (as the magnet moves).

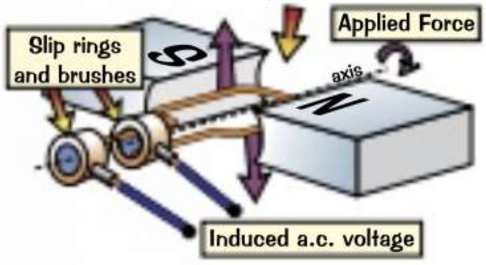
3) You can test this by connecting an ammeter to a conductor and moving the conductor through a magnetic field (or moving a magnet through the conductor). The ammeter will show the magnitude and direction of the induced current.
4) If the direction of movement is reversed, then the induced voltage/current will be reversed too.

To get a bigger voltage, you can increase...
1) The STRENGTH of the MAGNET
2) The number of TURNS on the COIL
3) The SPEED of movement

Think about the simple electric motor — you've got a current in the wire and a magnetic field, which causes movement. Well, a generator works the opposite way round — you've got a magnetic field and movement, which induces a current.

A.C. Generators — Just Turn the Coil and There's a Current

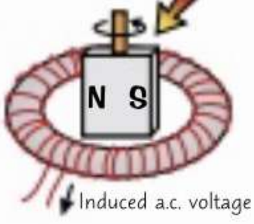
Coil rotated in a magnetic field.

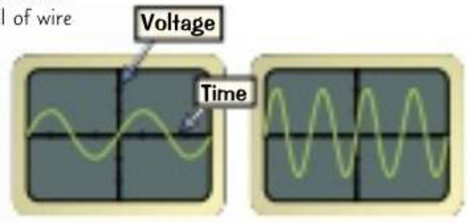


You've already met generators and electromagnetic induction — this is a bit more detail about how a simple generator works.

1) Generators rotate a coil in a magnetic field (or a magnet in a coil).
2) Their construction is pretty much like a motor.
3) As the coil spins, a current is induced in the coil. This current changes direction every half turn.
4) Instead of a split-ring commutator, a.c. generators have slip rings and brushes so the contacts don't swap every half turn.
5) This means they produce a.c. voltage, as shown by these CRO displays. Note that faster revolutions produce not only more peaks but higher overall voltage too.
6) Power stations use a.c. generators to produce electricity — they just get the energy needed to turn the coil or magnetic field in different ways.

Magnet rotated in a coil of wire





original   faster revs

How do you make a current in a pond — by in-duck-tion...

Induction's simple enough: conductor + magnetic field + movement = voltage (& current if there's a circuit).

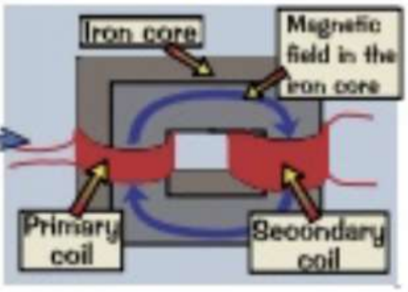
Q1 What is electromagnetic induction? [1 mark]

Transformers

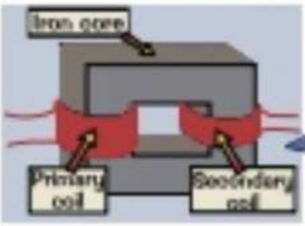
Transformers only work with an alternating current. Try it with a standard battery and you'll be there for days.

Transformers Change the Voltage — but Only Alternating Voltages

1) Transformers change the size of the voltage of an alternating current.
2) They all have two coils, the primary and the secondary, joined with an iron core.
3) When an alternating voltage is applied across the primary coil, the magnetically soft (iron) core magnetises and demagnetises quickly. This induces an alternating voltage in the secondary coil (p.63).
4) The ratio between the primary and secondary voltages is the same as the ratio between the number of turns on the primary and secondary coils.



STEP-UP TRANSFORMERS increase the voltage. They have more turns on the secondary coil than the primary coil.



STEP-DOWN TRANSFORMERS decrease the voltage. They have more turns on the primary coil than the secondary.

The Transformer Equation — Use it Either Way Up

1) You can calculate the output voltage from a transformer from the input voltage and the number of turns on each coil.

$$\frac{\text{Input (Primary) Voltage}}{\text{Output (Secondary) Voltage}} = \frac{\text{Number of turns on Primary}}{\text{Number of turns on Secondary}}$$

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

OR

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

2) This equation can be used either way up — there's less rearranging to do if you put whatever you're trying to calculate (the unknown) on the top.
3) The number of turns on the secondary coil divided by the number of turns on the primary coil is called the turns ratio.

Transformers are Nearly 100% Efficient So "Power In = Power Out"

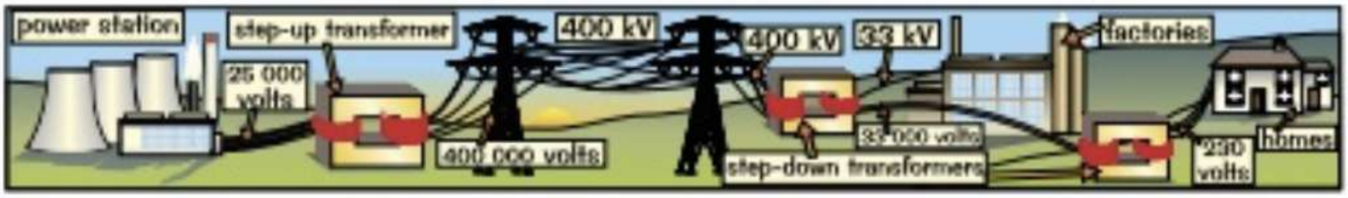
The formula for power supplied is: Power = Voltage × Current
or: $P = V \times I$.
So you can rewrite input power = output power as:

primary current secondary voltage

$$V_pI_p = V_sI_s$$

primary voltage secondary current

Transformers Make Transmitting Mains Electricity More Efficient



Step-up and step-down transformers are used when transmitting electricity across the country:

1) The voltage produced by power stations is too low to be transmitted efficiently. Power = VI, so the lower the voltage the higher the current for a given amount of power, and current causes wires to heat up.
2) A step-up transformer is used to boost the voltage before it is transmitted.
3) Step-down transformers are used at the end of the journey to reduce the voltage so it's more useful and safer to use.

I once had a dream about transforming into a hamster...

...but that's a story for another time. For now, better get revising what transformers do, and why they're useful.

Q1 A transformer with 320 turns on its primary coil and 770 turns on its secondary coil has a primary voltage of 65 V. Calculate the secondary voltage. [3 marks]

Revision Questions for Section 6

Just what you were waiting for — a whole list of lovely questions to try. Better get them over with then...

- Try these questions and tick off each one when you get it right.
- When you've done all the questions for a topic and are completely happy with it, tick off the topic.

Magnets and Magnetic Fields (p.59) ☐

1) Sketch a diagram showing the magnetic field produced by a bar magnet. ☐

2) Briefly describe an experiment to investigate the magnetic field pattern around a permanent bar magnet. ☐

3) Sketch a diagram showing how you can produce a uniform magnetic field using two bar magnets. ☐

Electromagnetism (p.60-62) ☐

4) Sketch the magnetic field produced by:
a) A straight wire. b) A flat loop of wire. c) A solenoid. ☐

5) What is an electromagnet? ☐

6) Give one example of a soft magnetic material and one example of a hard magnetic material. ☐

7) What's the motor effect? ☐

8) What will happen to a charged particle moving through a magnetic field? ☐

9) Name two factors that increase the strength of the force on a current-carrying wire in a magnetic field. ☐

10) What's a split-ring commutator used for in an electric motor? ☐

11) Sketch a labelled diagram of a loudspeaker and briefly explain how it works due to the motor effect. ☐

Electromagnetic Induction (p.63) ☐

12) Briefly describe how a voltage can be induced using a coil of wire and a magnet. ☐

13) Give three factors you could change to increase the size of an induced voltage. ☐

14) Sketch a labelled diagram of an a.c. generator and briefly explain how it works. ☐

Transformers (p.64) ☐

15) Sketch a diagram of a step-up transformer. ☐

16) How does a transformer change the voltage of an electricity supply? ☐

17) A transformer has 10 turns on the primary coil and 50 turns on the secondary coil. If the primary voltage is 30 V, what will the secondary voltage be? ☐

18) The power output of a transformer is 6000 W. If the input voltage is 30 000 V, what is the input current? ☐

19) How are transformers used in the transmission of electricity across long distances? ☐

Radioactivity

Although you can't see it, nuclear radiation is all around us all the time — important stuff if you ask me.

At the Centre of Every Atom is a Nucleus

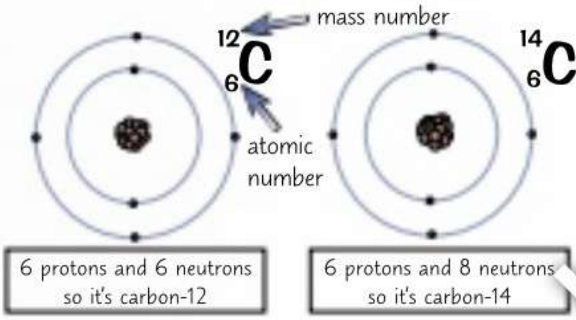
Protons and electrons have an equal but opposite charge.

1) The nucleus of an atom contains protons and neutrons. It makes up most of the mass of the atom, but takes up virtually no space — it's tiny.
2) The number of protons in the nucleus is called the atomic number, or proton number. The total number of protons and neutrons in the nucleus is called the mass number, or nucleon number.
3) The electrons are negatively charged and really really small. They whizz around the outside of the atom. Their paths take up a lot of space, giving the atom its overall size (though it's mostly empty space).
4) Atoms are neutral, so the number of protons = the number of electrons.

A Tom.

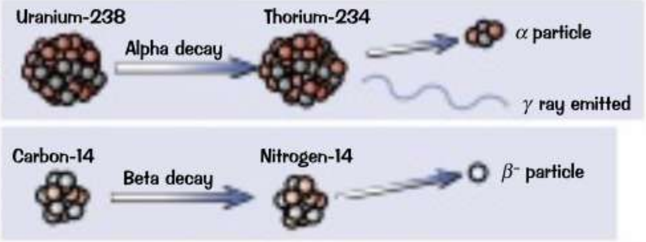
Isotopes are Atoms with Different Numbers of Neutrons

1) Many elements have a few different isotopes. Isotopes are atoms with the same number of protons (i.e. the same atomic number) but a different number of neutrons (so a different mass number).
2) E.g. there are two common isotopes of carbon. Carbon-14 has two more neutrons than 'normal' carbon (carbon-12).
3) Usually each element only has one or two stable isotopes — like carbon-12. The other isotopes tend to be radioactive — the nucleus is unstable, so it decays (breaks down) and emits radiation. Carbon-14 is an unstable isotope of carbon.



Radioactive Decay is a Random Process

1) The nuclei of unstable isotopes break down at random. If you have 1000 unstable nuclei, you can't say when any one of them is going to decay, and you can't do anything at all to make a decay happen.
2) Each nucleus just decays quite spontaneously in its own good time. It's completely unaffected by physical conditions like temperature or by any sort of chemical bonding etc.
3) When the nucleus does decay it spits out one or more types of radiation — alpha (α), beta (β^-), gamma (γ) or neutrons (n) (see next page).
4) In the process, the nucleus often changes into a new element.



Background Radiation is Everywhere All the Time

There's (low-level) background nuclear radiation all around us all the time. It comes from:

- substances here on Earth — some radioactivity comes from air, food, building materials, soil, rocks...
- radiation from space (cosmic rays) — mostly from the Sun,
- living things — there's a little bit of radioactive material in all living things,
- radiation due to human activity — e.g. fallout from nuclear explosions, or nuclear waste (though this is usually a tiny proportion of the total background radiation).

Isotopes of an outfit — same dress, different accessories...

Lots of new words to remember on this page. Isotopes, atomic number, alpha, beta.... make sure you know them all.

Q1 Which of the following represents an isotope of $^{14}_{7}N$: $^{15}_{7}N$ or $^{14}_{8}N$? Explain your answer. [2 marks]

Ionising Radiation

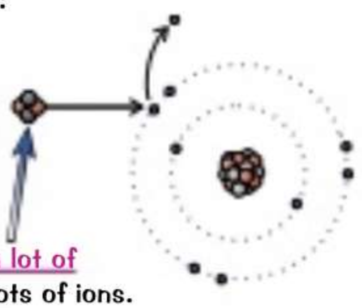
Alpha, beta and gamma are three types of ionising radiation. You need to remember what they are, how well they penetrate materials (including air), and their ionising power.

Nuclear Radiation Causes Ionisation

1) Nuclear radiation causes ionisation by bashing into atoms and knocking electrons off them. Atoms (with no overall charge) are turned into ions (which are charged) — hence the term "ionisation".
2) There's a pattern: the further the radiation can penetrate before hitting an atom and getting stopped, the less damage it will do along the way and so the less ionising it is.
3) Ionising radiation can be detected using either a Geiger-Müller detector (see p.68) or photographic film.
4) You need to know lots of details about three different types of ionising radiation:

Alpha Particles are Helium Nuclei $^{4}_{2}\text{He}$

There's more on penetrating power on the next page.



1) Alpha (α) particles are made up of 2 protons and 2 neutrons — they're big, heavy and slow-moving.
2) They therefore don't penetrate far into materials but are stopped quickly.
3) Because of their size they're strongly ionising, which means they bash into a lot of atoms and knock electrons off them before they slow down, which creates lots of ions.
4) Because they're electrically charged (with a positive charge), alpha particles are deflected (their direction changes) by electric and magnetic fields.
5) Emitting an alpha particle decreases the atomic number of the nucleus by 2 and the mass number by 4.

See page 68 for more.

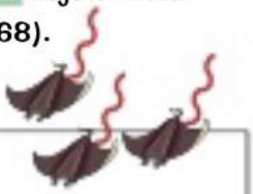
Beta Particles are Electrons $^{0}_{-1}\text{e}^{-}$

1) A beta (β^-) particle is an electron which has been emitted from the nucleus of an atom when a neutron turns into a proton and an electron.
2) When a beta particle is emitted, the number of protons in the nucleus increases by 1. So the atomic number increases by 1 but the mass number stays the same (p.68).
3) They move quite fast and they are quite small.
4) They penetrate moderately before colliding and are moderately ionising too.
5) Because they're charged (negatively), beta particles are deflected by electric and magnetic fields.

Gamma Rays are Very Short Wavelength EM Waves

Neutron radiation (where neutrons are emitted) is ionising too, but you don't need to know its properties — only how to balance neutron decay equations (see p.68).

1) In a way, gamma (γ) rays are the opposite of alpha particles. They have no mass — they're just energy (in the form of an EM wave — see p.28).
2) They can penetrate a long way into materials without being stopped.
3) This means they are weakly ionising because they tend to pass through rather than collide with atoms. But eventually they hit something and do damage.
4) Gamma rays have no charge, so they're not deflected by electric or magnetic fields.
5) Gamma emission always happens after beta or alpha decay. You never get just gamma rays emitted.
6) Gamma ray emission has no effect on the atomic or mass numbers of the isotope (p.68). If a nucleus has excess energy, it loses this energy by emitting a gamma ray.



Learn your alphabet-agamma...

Make sure you remember what each particle is made up of. It'll help you balance nuclear equations on the next page.

Q1 Explain what is meant by ionisation. [1 mark]

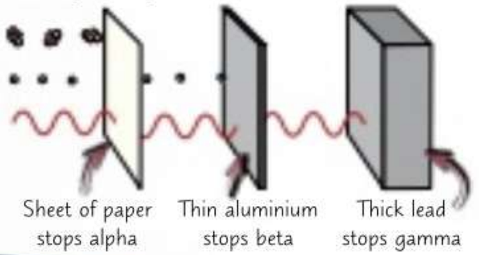
Q2 Name four types of ionising radiation. [1 mark]

Investigating Radiation & Nuclear Equations

As you've seen, different radiation can penetrate by different amounts. This means that they can pass through different materials. Don't believe me? Ok, you try it.

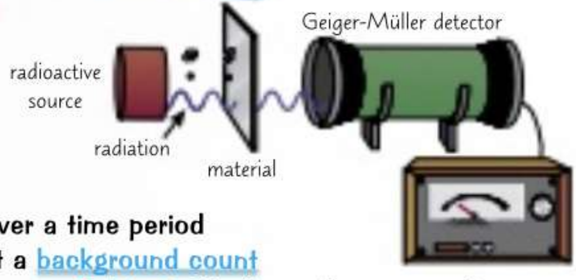
You Can Identify the Type by its Penetrating Power

1) Alpha particles are blocked by paper, skin, or a few cm of air.
2) Beta particles are blocked by thin metal.
3) Gamma rays are blocked by thick lead or very thick concrete.



You can Investigate the Penetration of Radiation

PRACTICAL



1) You can detect ionising radiation with a Geiger-Müller detector. A Geiger-Müller detector gives a count rate — the number of radioactive particles reaching it per second.
2) Set up the equipment as shown on the right, so that when nothing is placed between the source and detector, the counter records a high count rate.
3) Remove the source to measure the background count (p.66) over a time period (e.g. 30 seconds). Divide your count by the time period to get a background count rate (in counts per second). Do this three times and find the mean. Subtract this from all your results.
4) Replace the source and measure the count rate (minus the background count rate) with no material present three times and take a mean. Then insert different materials between the source and detector. Record the count rate for each material three times and find the mean.
5) If the count rate remains about the same when the material is inserted, then the radiation can penetrate the material. If it drops by a large amount, then the radiation is being absorbed and blocked by the material. If it drops to zero after the background count is subtracted, the radiation is being completely absorbed.
6) Repeat this experiment with different sources to investigate the penetrations of different kinds of radiation.

Radioactive sources can be dangerous if you don't use them properly (p.71):

- Radioactive sources should be kept in a lead-lined box when not in use.
- They should only be picked up using long-handled tongs or forceps.
- Take care not to point them at anyone, and keep a safe distance from them.

You can also investigate this using a computerised radiation simulator. Doing it in the lab requires lots of work with dangerous radioactive sources, so you might have simulated it in class instead.

Balancing Nuclear Equations

1) You can write equations for nuclear reactions — just like you can for chemical reactions.
2) The overall charge and mass have to be the same after a nuclear reaction as they were before.
3) The charge on a nucleus or particle is equal to the atomic number, and its mass is equal to the mass number. So the totals of the atomic and mass numbers have to be the same on both sides of the equation:

Alpha-emission:

mass number decreases by 4

$${}^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$$

atomic number decreases by 2

Beta-emission:

mass number stays the same

$${}^{187}_{75}\text{Re} \longrightarrow {}^{187}_{76}\text{Os} + {}^{0}_{-1}\text{e}$$

atomic number increases by 1

Gamma-emission:

mass number stays the same

$${}^{99}_{43}\text{Tc} \longrightarrow {}^{99}_{43}\text{Tc} + {}^{0}_{0}\gamma$$

atomic number stays the same

Neutron-emission:

mass number decreases by 1

$${}^{13}_{4}\text{Be} \longrightarrow {}^{12}_{4}\text{Be} + {}^{1}_{0}\text{n}$$

atomic number stays the same

Keep balanced during revision and practise nuclear equations...

Nuclear equations are simple, but that doesn't mean you shouldn't practise them. Try these questions on for size.

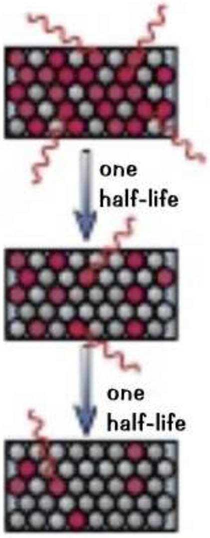
Q1 What type of radiation is given off in this decay? ${}^{8}_{3}\text{Li} \rightarrow {}^{8}_{4}\text{Be}$ + radiation. [1 mark]

Q2 Write the nuclear equation for ${}^{219}_{86}\text{Rn}$ decaying to polonium (Po) by emitting an alpha particle. [3 marks]

Half-Life

Half-life is the time it takes for a radioactive material to lose half of its radioactivity. Simple really.

The Radioactivity of a Sample Always Decreases Over Time



1) This is pretty obvious when you think about it. Each time a decay happens and an alpha or beta particle or gamma ray is given out, it means one more radioactive nucleus has disappeared.
2) Obviously, as the unstable nuclei all disappear, the activity (the number of decays in a given time) will decrease. So the older a sample becomes, the less radiation it will emit.
3) How quickly the activity drops off varies a lot. For some isotopes it takes just a few hours before nearly all the unstable nuclei have decayed, whilst others last for millions of years.
4) The problem with trying to measure this is that the activity never reaches zero, which is why we have to use the idea of half-life to measure how quickly the activity drops off.
5) Learn this important definition of half-life:

   Half-life is the time taken for half of the radioactive atoms now present to decay.

6) Another definition of half-life is:
   "The time taken for the activity (or count rate) to fall by half". Use either.
7) A short half-life means the activity falls quickly, because lots of the nuclei decay quickly.
8) A long half-life means the activity falls more slowly because most of the nuclei don't decay for a long time — they just sit there, basically unstable, but kind of biding their time.

For any particular isotope, the half-life is always the same.

Example: The activity of a radioactive isotope is 640 Bq. Two hours later it has fallen to 40 Bq. Find the half-life of the sample.

Radioactivity is measured in becquerels (Bq). 1 Bq is 1 decay per second.

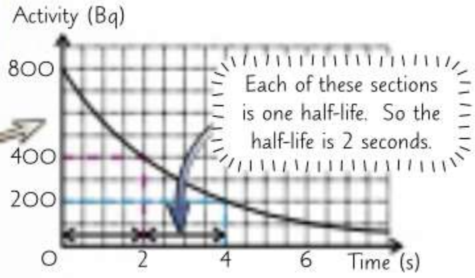
To answer, go through it in short simple steps like this:

INITIAL count:		after ONE half-life:		after TWO half-lives:		after THREE half-lives:		after FOUR half-lives:
640	(÷2)→	320	(÷2)→	160	(÷2)→	80	(÷2)→	40

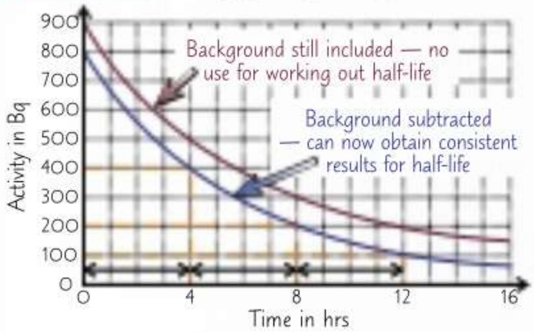
Notice the careful step-by-step method, which tells us it takes four half-lives for the activity to fall from 640 to 40. So two hours represents four half-lives, so the half-life is 30 minutes.

Measuring the Half-Life of a Sample Using a Graph

1) This can only be done by taking several readings of a source's activity, usually using a Geiger-Müller (G-M) detector. The results can then be plotted as a graph, which will always be shaped like this.
2) The half-life is found from the graph, by finding the time interval on the bottom axis corresponding to a halving of the activity on the vertical axis. Easy peasy really.



Each of these sections is one half-life. So the half-life is 2 seconds.



Background still included — no use for working out half-life

Background subtracted — can now obtain consistent results for half-life

You need to make sure you've subtracted the background count from your readings before you plot the graph (see p.66). If you don't, you'll get an incorrect value for half-life, and it'll be different for each measurement you take from the graph. Realistically, the only difficult bit is actually remembering about that for your exam, should they ask you about it. They could also test that idea in a calculation question.

Half-life of a box of chocolates — about five minutes...

Half-life — the time for the number of radioactive nuclei, the activity or the count-rate to halve. Simple.

Q1 The initial activity of a sample is 40 Bq. Calculate the count-rate after three half-lives. [2 marks]

Uses of Nuclear Radiation

Nuclear radiation can be really useful — but you've got to be careful about what isotope you choose to use.

Medical Tracers Use Beta or Gamma Radiation

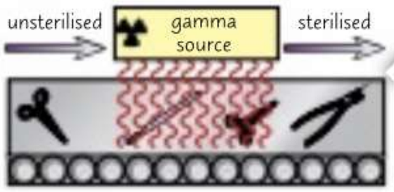
Beta and gamma will penetrate the skin and other body tissues. This makes them suitable as medical tracers:

1) A source which emits beta or gamma radiation is injected into the patient (or swallowed). The radiation penetrates the body tissues and can be detected externally. As the source moves around the body, the radiographer uses a detector and a computer to monitor its progress on a display.
2) Doctors use this method to check whether the organs of the body are working as they should.
3) The radioactive source has to have a short half-life, so that the initial levels are high enough to be easily detected, but the radioactivity inside the patient quickly disappears.
4) An alpha source would be worse than useless as a medical tracer — useless because it would be stopped by the body's tissues, so you'd never detect it externally, and worse than useless because its strong ionising power makes alpha radiation really harmful if it gets inside you (see page 71).

Radiation is Also Used to Treat Cancer

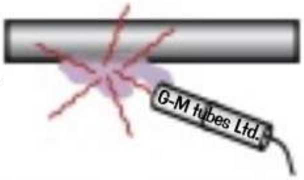
1) You'll see on the next page that ionising radiation can kill or damage cells and tissues, which can cause cancer. But once the cancer's started, ionising radiation can also be used to treat it.
2) Radiotherapy kills the cancer cells and stops them dividing — it involves using a high dose of gamma rays, carefully directed to zap the cells in the tumour while minimising the dose to the rest of the body.

Food and Equipment can be Sterilised Using Gamma Rays

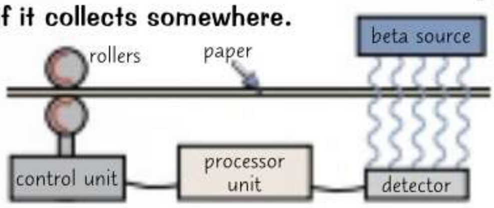


1) Food can be irradiated with (p.71) a high dose of gamma rays to kill all microbes, so that it doesn't go bad as quickly as it would do otherwise.
2) Similarly, medical equipment can be sterilised using gamma rays.
3) Irradiation is a particularly good method of sterilisation because, unlike boiling, it doesn't involve high temperatures, so fresh fruit or plastic instruments can be totally sterilised without being damaged.
4) The radioactive source used for this needs to be a very strong emitter of gamma rays with a reasonably long half-life (at least several months) so that it doesn't need replacing too often.

Radiation is Used in Industry for Tracers and Thickness Gauges



1) Gamma emitting tracers are used in industry to detect leaks in underground pipes.
2) The source is allowed to flow down the pipe and a detector is used above ground. Gamma is used because it can pass through any rocks or earth surrounding the pipe.
3) If there's a crack in the pipe, more radiation will collect outside the pipe, and the detector will show extra high radioactivity at that point.
4) It should have a short half-life so as not to cause a long-term hazard if it collects somewhere.



5) Beta radiation is used in thickness control. You direct radiation through the stuff being made (e.g. paper), and put a detector on the other side, connected to a control unit. When the detected radiation level changes, it means the paper is coming out too thick or too thin, so the control unit adjusts the rollers to give the correct thickness.
6) It needs to be a beta source, because then the paper will partly block the radiation (see p.68). If it all goes through (or none of it does), then the reading won't change at all as the thickness changes.

Choose your source carefully — I like ketchup on ice cream...

To make use of radiation, you've got to match the requirements of the job to the properties of your source.

Q1 Explain why sources of alpha radiation cannot used to measure the thickness of aluminium. [2 marks]

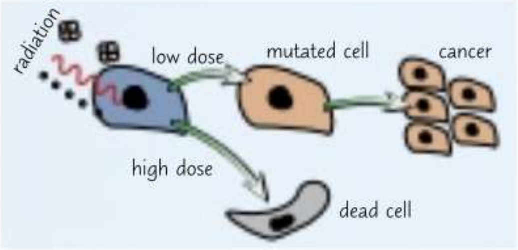
Risks from Nuclear Radiation

Radiation's dangerous and useful at the same time — it can both cause and cure cancer, for instance.

Ionising Radiation Can Damage Cells and Tissues

1) Beta and gamma can penetrate the skin and soft tissues to reach the delicate organs inside the body. This makes beta and gamma sources more hazardous than alpha when outside the body. If they get inside (e.g. swallowed or breathed in), their radiation mostly passes straight out without doing much damage.
2) Alpha radiation can't penetrate the skin, but it's very dangerous if it gets inside the body. Alpha sources do all their damage in a very localised area.
3) When radiation enters your body, it will collide with molecules in your cells. These collisions cause ionisation, which damages or destroys the molecules. The extent of the harmful effects depends on how much exposure you have to the radiation, and its energy and penetration.
4) Lower doses tend to cause minor damage without killing the cell. This can cause mutations in cells which then divide uncontrollably — this is cancer.
5) Higher doses tend to kill cells completely, causing radiation sickness if a large part of your body is affected at the same time.

The properties of alpha, beta and gamma are on page 67.



Exposure to Radiation is called Irradiation

1) Objects near a radioactive source are irradiated by it. This simply means they're exposed to it (we're always being irradiated by background radiation sources).
2) Irradiating something does not make it radioactive (and won't turn you into a superhero).
3) Keeping sources in lead-lined boxes, standing behind barriers or being in a different room and using remote-controlled arms are all ways of reducing the risk of irradiation.

Contamination is Radioactive Particles Getting onto Objects

1) If unwanted radioactive atoms get onto or into an object, the object is said to be contaminated. E.g. if you touch a radioactive source without wearing gloves, your hands would be contaminated.
2) These contaminating atoms might then decay, releasing radiation which could cause you harm.
3) Contamination is especially dangerous because radioactive particles could get inside your body.
4) Gloves and tongs should be used when handling sources, to avoid particles getting stuck to your skin or under your nails. Some industrial workers wear protective suits and masks to stop them breathing in particles.

Radioactive Waste is Difficult to Dispose of Safely

1) Most radioactive waste from nuclear power stations and hospitals is 'low-level' (slightly radioactive) — things like clothing, syringes, etc. This kind of waste can be disposed of by burying it in secure landfill sites.
2) High-level waste is the really dangerous stuff — a lot of it stays highly radioactive for tens of thousands of years, and so has to be treated very carefully. It's often sealed into glass blocks, which are then sealed in metal canisters. These could then be buried deep underground.
3) However, it's difficult to find suitable places to bury high-level waste. The site has to be geologically stable (e.g. not suffer from earthquakes), since big movements in the rock could disturb the canisters and allow radioactive material to leak out. If this material gets into the groundwater, it could contaminate the soil, plants, rivers, etc., and get into our drinking water.

Failing your exams would be a high-level waste of time...

Make sure you can describe how to reduce the risks of nuclear radiation, and why it's so important that you do.

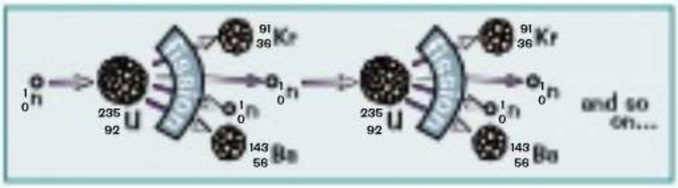
Q1 Explain the difference between contamination and irradiation. [1 mark]

Q2 Give three safety measures that should be followed to avoid the risk of irradiation [2 marks]

Nuclear Fission and Fusion

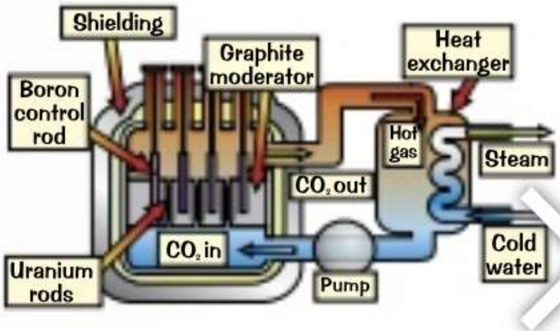
Loads of energy's released either when you break apart really big nuclei or join together really small nuclei.

Nuclear Power Stations use Nuclear Fission Chain Reactions



1) Nuclear fission is the splitting of an atom, which releases energy. It can be spontaneous, but in a nuclear reactor it's made to happen — e.g. to uranium-235.
2) If a slow-moving neutron is absorbed by a uranium-235 nucleus, the nucleus can split.
3) Each time this happens, it spits out a small number of neutrons. These might go on to hit other uranium-235 nuclei, causing them to split also... and so on and so on. This is a chain reaction.
4) When uranium-235 splits in two it will form two new daughter nuclei, both lighter elements than uranium.
5) These new nuclei are usually radioactive. This is the big problem with nuclear power — radioactive waste.
6) Each nucleus splitting gives out a lot of energy — this energy is in the kinetic energy stores of the fission products (the daughter nuclei and the neutrons).
7) In a reactor, this energy is transferred to thermal energy stores to produce steam to drive a turbine (see below).

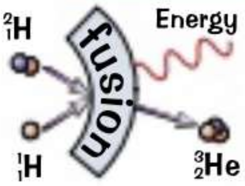
Nuclear Reactors Have to Work Safely



1) The neutrons released by fission reactions in a nuclear reactor have a lot of energy. In order to be absorbed by uranium nuclei and sustain the chain reaction, they need to be slowed down.
2) The moderator, usually graphite or water, slows down neutrons.
3) Control rods, often made of boron, limit the rate of fission by absorbing excess neutrons.
4) The high-energy neutrons and gamma rays (energy) released in fission are highly penetrating ionising radiation. Shielding has to be used to absorb the ionising radiation. The shielding is usually a thick concrete structure, which may also contain lead or other metals.
5) A substance (e.g. CO_2) pumped round the reactor transfers the energy (by heating) to the water in the heat exchanger. The water turns to steam, which turns a turbine, which turns a generator and generates electricity.

Nuclear Fusion — Joining Small Nuclei

1) Nuclear fusion is the opposite of nuclear fission. In nuclear fusion, two light nuclei collide at high speed and join (fuse) to create a larger, heavier nucleus. E.g. hydrogen nuclei can fuse to produce a helium nucleus.



2) This heavier nucleus doesn't have as much mass as the two separate, light nuclei did. Some of the mass of the lighter nuclei is converted to energy (don't panic, you don't need to know how). This energy is then released as radiation.
3) Fusion releases a lot of energy (more than fission for a given mass of fuel) — all the energy released in stars comes from fusion.
4) The big problem is that fusion only happens at really high pressures and temperatures (about 10 000 000 °C). This is because the positively charged nuclei have to get very close to fuse, so they need to be moving very fast to overcome the strong force due to electrostatic repulsion (p.23).
5) So far, scientists haven't found a way of using fusion to generate energy for us to use. The temperatures and pressures needed for fusion are so high that fusion reactors are really hard and expensive to build.

BEWARE: the filling of this fruit pie is hotter than the conditions needed for fusion.

Pity they can't release energy by confusion...*

Nuclear reactors are carefully-designed to release energy safely, but we've not worked out how to do that with fusion yet.

Q1 Draw a diagram showing how fission can lead to a chain reaction. [3 marks]

Q2 Explain why fusion only occurs at high temperatures and pressures. [2 marks]

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*There'd be plenty of physics books to use as fuel.

Revision Questions for Section 7

Well, that wraps up Section 7. Now a reward for ploughing through loads of pages of pretty intense science — a page of lovely questions. Okay, I know it seems a little daunting, but it's absolutely vital to check that you've learnt all the right stuff..

- Try these questions and tick off each one when you get it right.
- When you've done all the questions for a topic and are completely happy with it, tick off the topic.

Nuclear Radiation (p.66-68) ☐

1) What is the atomic number of a nucleus? ☐
2) What is the mass number of a nucleus? ☐
3) What are isotopes of an element? ☐
4) Name four things that may be emitted during radioactive decay. ☐
5) Briefly describe what background radiation is and where it comes from. ☐
6) Describe what alpha, beta and gamma radiation are. ☐
7) Which is the most ionising out of alpha, beta and gamma radiation? ☐
8) Describe how the mass and atomic numbers of an atom change if it emits an alpha particle. ☐
9) In what type of nuclear decay does a neutron change into a proton within the nucleus? ☐
10) What type of nuclear decay doesn't change the mass or charge of the nucleus? ☐
11) What type of radiation is stopped by paper? ☐
12) Give two ways you can detect ionising radiation. ☐
13) What quantities need to be the same on each side of a nuclear equation? ☐

Half-life (p.69) ☐

14) What is meant by the 'activity' of a radioactive source? ☐
15) Define half-life. ☐
16) True or false? A short half-life means a small proportion of the atoms are decaying per second. ☐

Uses and Risks of Nuclear Radiation (p.70-71) ☐

17) Briefly describe two uses of nuclear radiation in medicine. ☐
18) Explain why alpha radiation could not be used to check the thickness of metal sheets. ☐
19) Other than thickness gauges, give one other use of nuclear radiation in industry. ☐
20) Why is nuclear radiation dangerous to living organisms? ☐
21) Explain why radioactive waste is difficult to dispose of safely. ☐

Fusion and Fission (p.72) ☐

22) What are the products of the nuclear fission of uranium-235? ☐
23) True or false? The fission products of uranium-235 are also radioactive. ☐
24) Briefly describe how a chain reaction is set up in a nuclear reactor. ☐
25) What job do control rods, moderators and shielding do in a nuclear reactor? ☐
26) State the conditions needed to create a fusion reaction. ☐

The Universe

There's all sorts of exciting stuff in the universe... Our whole solar system is just part of a huge galaxy. And there are billions upon billions of galaxies. You should be realising now that the universe is pretty darn big...

We are Part of the Milky Way Galaxy

1) The universe is a large collection of billions of galaxies.
2) A galaxy is a large collection of stars.
3) Our Sun is just one of many billions of stars which form the Milky Way galaxy. Our Sun is about halfway along one of the spiral arms of the Milky Way.
4) The distance between neighbouring stars in the galaxy is often millions of times greater than the distance between planets in our solar system.
5) The force which keeps the stars together in a galaxy is gravity, of course. And like most things in the universe, galaxies rotate — a bit like a Catherine wheel.
6) Galaxies themselves are often millions of times further apart than the stars are within a galaxy.
7) So the universe is mostly empty space and is really, really BIG.

You are here.

Our Solar System has One Star — The Sun

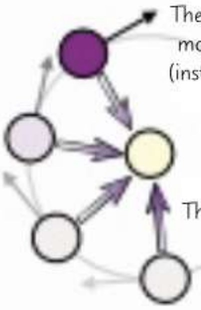
A satellite is an object that orbits a second, more massive object.

Our solar system is all the stuff that orbits the Sun. This includes things like:

1) Planets — these are large objects that orbit a star. The eight planets in our solar system are, in order (from the Sun outwards): Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune.
2) Dwarf planets, like our pal Pluto. These are planet-like objects that aren't big enough to be planets.
3) Moons — these orbit planets with almost circular orbits. They're a type of natural satellite (i.e. they're not man-made).
4) Artificial satellites (ones humans have built) that usually orbit the Earth in fairly circular orbits.
5) Asteroids — lumps of rock and metal that orbit the Sun. They're usually found in the asteroid belt.
6) Comets — lumps of ice and dust that orbit the Sun. Their orbits are usually highly elliptical (a very stretched out circle) — some travel from near to the Sun to the outskirts of our solar system.

Gravity Provides the Force That Creates Orbits

1) The planets move around the Sun in almost circular orbits (same goes for the Moon around the Earth).
2) If an object is travelling in a circle it is constantly changing direction (and so constantly accelerating), which means there must be a force acting on it.
3) The force causing this is a centripetal force. It acts towards the centre of the circle.
4) This force would cause the object to just fall towards whatever it was orbiting, but as the object is already moving, it just causes it to change its direction.
5) The object keeps accelerating towards what it's orbiting but the instantaneous velocity (which is at a right angle to the acceleration) keeps it travelling in a circle.
6) The force that makes this happen is provided by the gravitational force (gravity). The gravitational attraction of the Sun keeps the planets and comets in their orbits around it.
7) Satellites are kept in their orbits around planets by the gravitational attraction of the planet.



The planet is 'trying' to move in this direction (instantaneous velocity).

The force is always towards the centre of the circle.

Gravity leads to orbits that are either circles or ellipses — see p.75.

Revision's hard work — you've got to plan et...

Make sure you know what orbits what and how to tell a moon from a planet. Then have a go at these questions.

Q1 Give the name of the galaxy that our solar system is located in. [1 mark]

Q2 Explain how the gravitational force keeps an object in orbit. [3 marks]

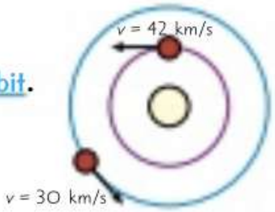
Gravity and Orbits

So as well as keeping you grounded, gravity also keeps the Earth moving around the Sun. Nifty stuff.

The Force due to Gravity Depends on Mass and Distance

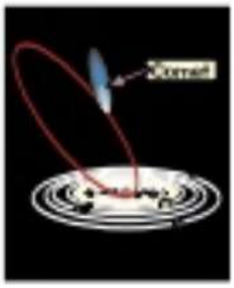
1) Back on page 3 you saw that the weight (i.e. the force on an object due to gravity) of any object varies depending on the strength (g) of the gravitational field that it is in.
2) Gravitational field strength depends on the mass of the body creating the field. The larger the mass of the body, the stronger its gravitational field. (The Earth is more massive than the Moon, so an object would weigh more on Earth than it would on the Moon.)
3) Gravitational field strength also varies with distance. The closer you get to a star or planet, the stronger the gravitational force is.
4) The stronger the force, the larger the instantaneous velocity needed to balance it.
5) So the closer to a star or planet you get, the faster you need to go to remain in orbit.
6) For an object in a stable orbit, if the speed of the object changes, the size (radius) of its orbit must do so too. Faster moving objects will move in a stable orbit with a smaller radius than slower moving ones.

The fact that different planets orbit the Sun at different speeds means that the distances between planets vary over time.



There are Different Types of Orbit

1) The orbits of moons and planets are usually slightly elliptical.
2) Comets orbit the Sun, but have very elliptical (elongated) orbits with the Sun at one focus (near one end of the orbit).
3) Comets have orbital periods much longer than the Earth, as they travel from the outer edges of our solar system. A comet travels much faster when it's nearer the Sun than it does in the more distant parts of its orbit. That's because the increased pull of gravity makes it speed up the closer it gets to the Sun.
4) Some artificial Earth satellites have an orbital period of exactly one day. They're called geostationary satellites, and are useful in communications because they're always over the same part of the planet.



You can Calculate Orbital Speeds

1) You can calculate the speed of an orbit using the formula from page 1:

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

2) For a circular orbit, the distance travelled is the circumference of the orbit, which is given by the formula:

$$\text{distance} = 2 \times \pi \times \text{radius of orbit}$$

3) So the formula for the speed of an orbit is:

$$\text{orbital speed} = \frac{2 \times \pi \times \text{orbital radius}}{\text{time period}} \qquad v = \frac{2\pi r}{T}$$

Remember that 'r' is the distance between the centre of the planet or star and the object that is orbiting around it.

Example: Calculate the speed of a satellite orbiting above the Earth's surface at an altitude of 600 km. The radius of the Earth is 6400 km and the satellite takes 200 mins to orbit the Earth once.

First calculate r in m, r = 6400 + 600 = 7000 km = 7 000 000 m

Then find the time period in seconds, T = 200 × 60 = 12 000 s

So orbital speed, $v = \dfrac{2 \times \pi \times 7\,000\,000}{12\,000}$ = 3665.191... m/s = 3700 m/s (to 2 s.f.)

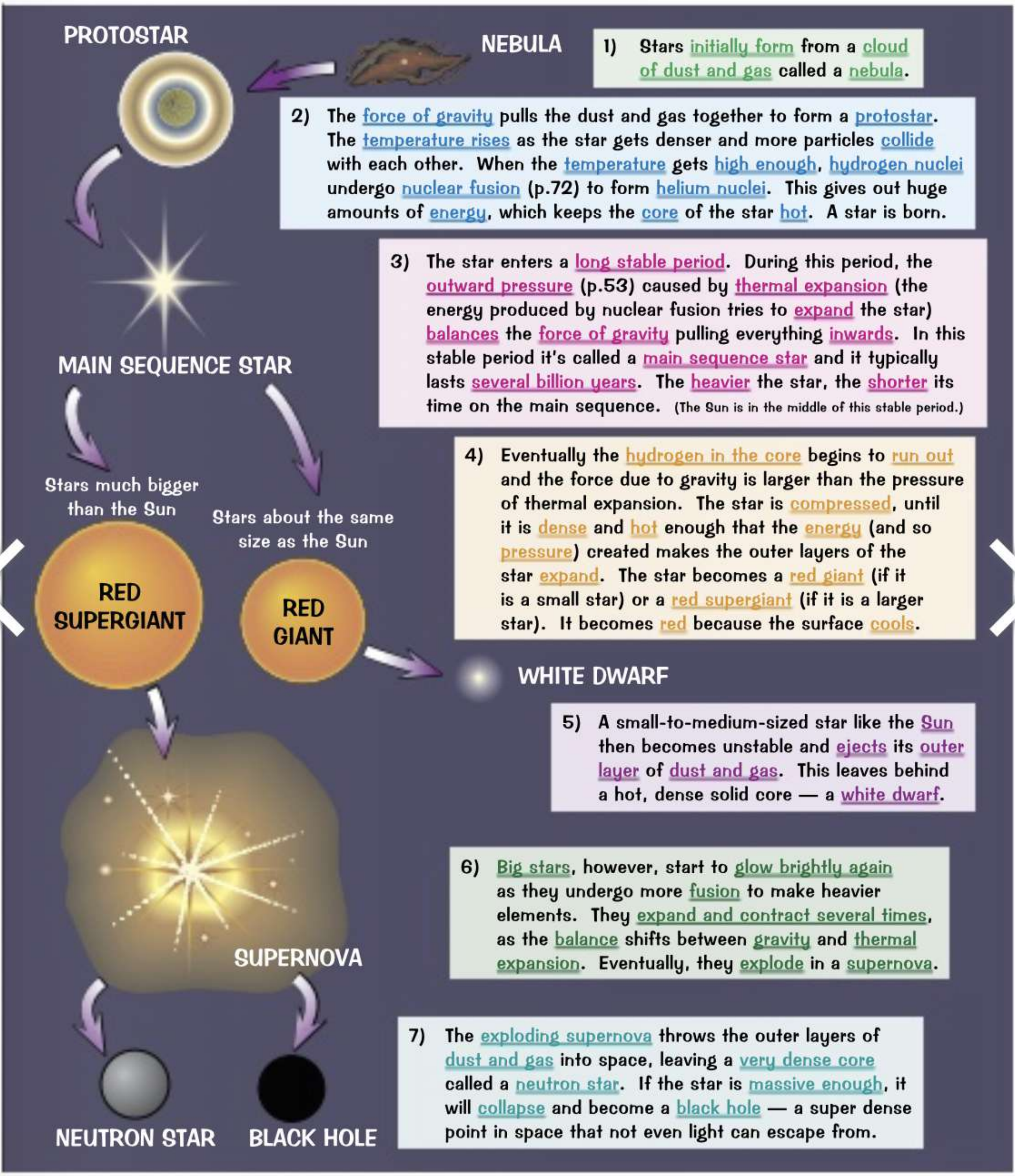
Forget the Sun, I'm pretty sure everything revolves around me...

Make sure you get your head around all this stuff about orbits — it's all about balancing the gravitational force and the object's speed. You'll be given the equation above in the exam, so you don't need to learn it, just know how to use it.

Q1 Calculate the orbital radius of a moon which orbits a planet in 30 hours with a speed of 1400 m/s. [3 marks]

Stellar Evolution

Stars go through many traumatic stages in their lives — just like teenagers.



1) Stars initially form from a cloud of dust and gas called a nebula.

2) The force of gravity pulls the dust and gas together to form a protostar. The temperature rises as the star gets denser and more particles collide with each other. When the temperature gets high enough, hydrogen nuclei undergo nuclear fusion (p.72) to form helium nuclei. This gives out huge amounts of energy, which keeps the core of the star hot. A star is born.

3) The star enters a long stable period. During this period, the outward pressure (p.53) caused by thermal expansion (the energy produced by nuclear fusion tries to expand the star) balances the force of gravity pulling everything inwards. In this stable period it's called a main sequence star and it typically lasts several billion years. The heavier the star, the shorter its time on the main sequence. (The Sun is in the middle of this stable period.)

4) Eventually the hydrogen in the core begins to run out and the force due to gravity is larger than the pressure of thermal expansion. The star is compressed, until it is dense and hot enough that the energy (and so pressure) created makes the outer layers of the star expand. The star becomes a red giant (if it is a small star) or a red supergiant (if it is a larger star). It becomes red because the surface cools.

5) A small-to-medium-sized star like the Sun then becomes unstable and ejects its outer layer of dust and gas. This leaves behind a hot, dense solid core — a white dwarf.

6) Big stars, however, start to glow brightly again as they undergo more fusion to make heavier elements. They expand and contract several times, as the balance shifts between gravity and thermal expansion. Eventually, they explode in a supernova.

7) The exploding supernova throws the outer layers of dust and gas into space, leaving a very dense core called a neutron star. If the star is massive enough, it will collapse and become a black hole — a super dense point in space that not even light can escape from.

It's the beginning of the world as we know it...

Pretty neat, seeing how stars like our Sun — which all of us rely on — were made all those years ago.

Q1 Describe the life cycle of a star the same size as our Sun, beginning from a nebula. [6 marks]

Classifying Stars

We need to be able to categorise and compare stars, so we can better understand our universe.

Stars can be Classified by their Colours

Colour	Surface Temperature
Blue	Hottest
White	
Yellow	
Orange	
Red	Coolest

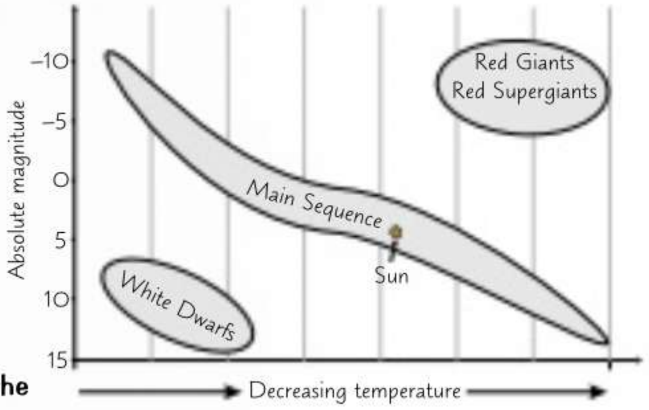
1) The colour of a star depends on the visible light it emits. All stars emit visible light, but how much it emits of each frequency depends on its surface temperature.
2) This means we can classify stars based on their colour. We use red, orange, yellow, white and blue. All stars of a similar colour will be of a similar temperature.
3) The hotter the star, the more light of higher frequencies it will emit.
4) A cool star will emit most of its visible light at the lowest frequency of visible light (i.e. red light — see page 28), and so it will appear red.
5) Orange stars are hotter than red stars, yellow stars are hotter than orange stars, and white stars are hotter than yellow stars. White stars emit all frequencies of visible light roughly equally.
6) Blue stars are hotter than white stars. They emit more high frequency light (blue, indigo and violet) than lower frequency ones (red and orange), and so they appear blue.

You can Compare Brightness using Absolute Magnitude

1) A star's brightness depends on its size and temperature. In general, the bigger and hotter the star, the brighter it is.
2) Classifying stars by brightness can be difficult, since the brightness they appear from Earth also depends on their distance from Earth. The closer the star, the brighter it appears.
3) If we just looked at brightness, we may end up classifying stars that are very far away but very bright in the same group as a star that is relatively dim, but nearby, which wouldn't be very useful.
4) To deal with this, we use a value called 'absolute magnitude'.
5) Absolute magnitude is a measure of how bright a given star would appear to be if it was a fixed distance from Earth (around 3.1×10^{17} m). This allows us to compare the brightness of stars without worrying about their relative distances from Earth.
6) Confusingly, the lower the absolute magnitude, the brighter the star. Very bright stars have a negative value for their absolute magnitudes. For example, the Sun has an absolute magnitude of around +5, while the Pole Star, one of the brightest looking stars in the night sky, has an absolute magnitude of around –4.

You can See Different Types of Star on the Hertzsprung-Russell Diagram

1) The Hertzsprung-Russell diagram is a graph of absolute magnitude against temperature for many, many stars.
2) There are clear groups on the graph that correspond to different periods in a star's life cycle.
3) Red giants and red supergiants are in the top-right. They are cool, but very large, and so are very bright.
4) White dwarfs are found in the bottom-left. They are very hot, but small, so are dim.
5) Main sequence stars span the whole range of the graph diagonally from top-left to bottom-right. Since all main sequence stars are roughly the same size, the brighter the star, the higher the temperature.



Welcome to Star Class. I've been told you're all pretty bright ...

This stuff's a little tricky. Be careful with absolute magnitude. Remember, the lower the number, the brighter the star.

Q1 Star A is orange, star B is white and star C is yellow. Which star has the highest surface temperature? [1 mark]

Red-shift

When we look at the light we detect from galaxies, everything's shifted from where it should be. Weird.

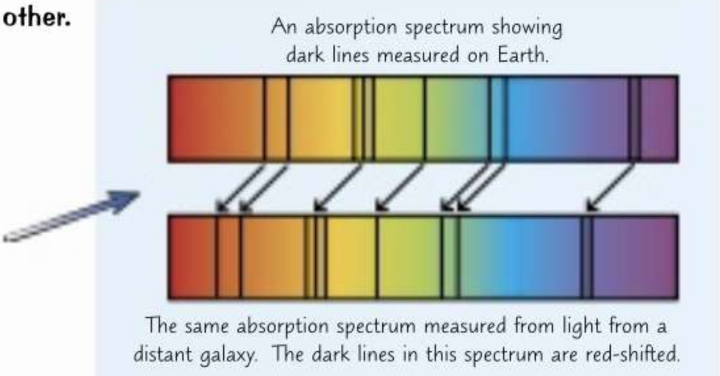
Waves are Affected by the Motion of the Source

1) As you saw on page 28, when a source of waves is moving relative to the observer, the waves will undergo a change in frequency and wavelength when they are observed, compared to when they were emitted — this is the Doppler Effect.
2) This happens with all types of waves, including light.
3) If the light source is moving away from you, the light it emits will be shifted towards the red end (i.e. the lower frequency end) of the visible part of the EM spectrum — this is red-shift.
4) Astronomers see this happening with light from stars. The light from distant stars is red-shifted — we observe light with a longer wavelength (lower frequency) than we would expect the stars to emit. The stars must be moving away from the Earth.

Light from Galaxies is Red-shifted

Most galaxies seem to be moving away from each other. There's good evidence for this:

1) Different elements absorb different frequencies (or wavelengths) of light.
2) When light is passed through a sample of an element, a pattern of dark lines is produced — with a dark line at each of the frequencies in the visible part of the EM spectrum that the element absorbs.
3) When we look at light from distant galaxies we see the same patterns but at slightly lower frequencies (and so longer wavelengths) than they should be.
4) The patterns have been shifted towards the red end of the spectrum — red-shift.



Calculating Red-shift

You need to be able to make calculations involving red-shift. The amount that light from a galaxy is red-shifted is determined by the following formula:

$$\frac{\text{change in wavelength}}{\text{reference wavelength}} = \frac{\text{velocity of a galaxy}}{\text{speed of light}}$$

$$\frac{\lambda - \lambda_0}{\lambda_0} = \frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

The 'reference wavelength' means the wavelength of the light when it was emitted, before it was red-shifted.

Example: A galaxy emits light with a wavelength of 410×10^{-9} m. The light is observed on Earth with a wavelength of 425×10^{-9} m. Calculate the velocity of the galaxy.

Rearrange the equation for velocity:

$$v = \frac{\lambda - \lambda_0}{\lambda_0} \times c = \frac{(425 \times 10^{-9}) - (410 \times 10^{-9})}{410 \times 10^{-9}} \times 3.00 \times 10^{8} = 1.0975... \times 10^{7}$$

$$= 1.10 \times 10^{7} \text{ m/s (to 3 s.f.)}$$

The speed of light is 3.00×10^8 m/s.

My brain's shifted towards the tired end of the spectrum...

Red-shift of light affects both wavelength and frequency, since light travels at a constant speed and $c = f\lambda$ (see p.27).

Q1 Calculate the observed change in wavelength of light that is emitted with a wavelength of 550×10^{-9} m from a galaxy that is moving away from Earth at a speed of 2.75×10^{7} m/s. [3 marks]

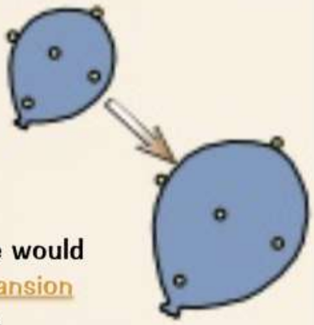
The Big Bang

'How it all began' is a tricky question that we just can't answer. Our best guess at the minute is the Big Bang.

Red-shift Suggests the Universe is Expanding

1) Measurements of the red-shift suggest that all the distant galaxies are moving away from us very quickly — and it's the same result whichever direction you look in.
2) More distant galaxies have greater red-shifts than nearer ones — they show a bigger observed increase in wavelength.
3) This means that more distant galaxies are moving away faster than nearer ones.
4) The inescapable conclusion appears to be that the whole universe (space itself) is expanding.

- Imagine a balloon covered with pompoms.
- As you blow into the balloon, it stretches.
  The pompoms move further away from each other.
- The balloon represents the universe and each pompom is a galaxy. As time goes on, space stretches and expands, moving the galaxies away from each other.
- This is a simple model (balloons only stretch so far, and there would be galaxies 'inside' the balloon too) but it shows how the expansion of space makes it look like galaxies are moving away from us.



There's Microwave Radiation from All Directions

This is another observation that scientists made. It's not super interesting in itself, but the model that explains it definitely is.

1) Scientists can detect low frequency microwave radiation coming from all directions and all parts of the universe.
2) It's known as the Cosmic Microwave Background (CMB) radiation.
3) For complicated reasons this background radiation is strong evidence for an initial Big Bang (see below). As the universe expands and cools, this background radiation 'cools' and drops in frequency.

This Evidence Suggests the Universe Started with a Bang

The galaxies are moving away from each other at great speed — suggesting something must have got them going from a single starting point. That 'something' was probably a big explosion — the Big Bang:

1) Initially, all the matter in the universe occupied a single point.
2) This tiny space was very dense and very hot.
3) This single point then 'exploded' — the Big Bang.
4) Space started expanding, and the expansion is still going on.

According to the Big Bang model, CMB radiation is the leftover energy of this initial explosion. Pretty neat, eh?

And it all started with the Big Bang...

The Big Bang model is the best one we've got to explain how the universe began, but it may need some tweaking in the future if we find new evidence it can't explain. Scientists, pfft, don't they ever finish anything?

P2 Q1 How does observed light from distant galaxies suggest that the universe is expanding? [4 marks] P2

Revision Questions for Section 8

Well, that wraps up Section 8. Now you've learnt the secrets of the cosmos, time to come back down to Earth and see how much of it is still orbiting around your brain.

- Try these questions and tick off each one when you get it right.
- When you've done all the questions for a topic and are completely happy with it, tick off the topic.

Galaxies, Our Solar System and Orbits (p.74-75) ☐

1) What is a galaxy? How many galaxies are in the universe? ☐
2) What force causes the orbits of moons, planets, comets and satellites? ☐
3) How do the orbits of comets differ from the orbits of moons and planets? ☐
4) The Earth is an average distance of 150 million km from the Sun.
   Find its orbital speed (assuming the orbit is circular). ☐

The Life Cycle and Classification of Stars (p.76-77) ☐

5) What is a nebula? ☐
6) What causes the rise in temperature that leads to nuclear fusion in a protostar? ☐
7) What causes a main sequence star to remain stable for a long time? ☐
8) What happens to a star about the same size as our Sun when it begins to run out of hydrogen? ☐
9) What is a white dwarf and how is it made? ☐
10) True or false? The Sun will eventually turn into a black hole. ☐
11) What colour of star has the lowest surface temperature? ☐
12) True or false? The higher the absolute magnitude, the brighter the star. ☐
13) Sketch the Hertzsprung-Russell diagram and label the regions of the graph
    corresponding to white dwarfs, main sequence stars, red giants and red supergiants. ☐

Red-shift and The Big Bang (p.78-79) ☐

14) What is red-shift? ☐
15) Calculate the original wavelength of light emitted from a galaxy that is moving away from Earth
    at 7.8×10^6 m/s and is red-shifted by 15×10^{-9} m when observed in a lab on Earth. ☐
16) True or false? Very distant galaxies are moving away faster than ones closer to us. ☐
17) What does CMB stand for? ☐
18) Briefly describe the ideas that make up the Big Bang theory. ☐

Experimental Know-How

Pro scientists need to know how to plan and carry out scientific experiments. They also need to know how to interpret and evaluate the data they get from those experiments. Unluckily for you, those pesky examiners think you should be able to do the same — don't worry though, that's what this topic's all about.

You Might Get Asked Questions on Reliability and Validity

1) RELIABLE results come from experiments that give similar data:

- each time the experiment is repeated (by you),
- each time the experiment is reproduced by other scientists.

2) VALID results are both reliable AND come from experiments that were designed to be a fair test.

In the exam, you could be asked to suggest ways to improve the reliability or validity of some experimental results. If so, there are a couple of things to think about:

Controlling Variables Improves Validity

1) A variable is something that has the potential to change, e.g. mass.
In a lab experiment you usually change one variable and measure how it affects another variable.

> Example: you might change only the mass of a toy car travelling down a ramp and measure how this affects its average speed.

2) To make it a fair test, everything else that could affect the results should stay the same — otherwise you can't tell if the thing you're changing is causing the results or not.

> Example continued: you need to keep the angle of the ramp the same, otherwise you won't know whether any change in average speed is caused by the change in angle of the ramp or the difference in mass of the car.

3) The variable you CHANGE is called the INDEPENDENT variable.

4) The variable you MEASURE is called the DEPENDENT variable.

5) The variables that you KEEP THE SAME are called CONTROL variables.

> Example continued:
> Independent variable = mass of toy car
> Dependent variable = average speed of toy car
> Control variables = angle of ramp, position of car release, material on ramp etc.

6) Make sure you think about how you'll control these variables, e.g. you could use a ruler to make sure you release the car from the same position each time.

7) Because you can't always control all the variables, you often need to use a CONTROL EXPERIMENT — an experiment that's kept under the same conditions as the rest of the investigation, but doesn't have anything done to it. This is so that you can see what happens when you don't change anything at all.

Carrying Out Repeats Improves Reliability

1) There will usually be differences between any sets of measurements you take, so you should make sure you repeat your measurements at least three times and calculate the mean (average).

2) Repeats with small differences between them show that your measurements are reliable — that they are similar and can be repeated.

Reliable results — they won't ever forget your birthday...

A typical exam question might describe an experiment, then ask you to suggest what variables need to be controlled. Don't panic, just use your scientific knowledge and a bit of common sense, e.g. if the experiment involves using a Geiger-Müller counter to detect radiation, you know that it's affected by the radiation source and the distance of the detector from the source, so these variables need to be kept constant (if you're not actually investigating one of them).

More Experimental Know-How

Thought you knew everything there was to know about experiments? Think again my friend...

You Might Have to Suggest Ways to Make an Experiment Safer

1) It's important that experiments are safe. If you're asked to suggest ways to make an experiment safer, you'll first need to identify what the potential hazards might be. Hazards include things like:

- Light sources, e.g. if a laser is directed into the eye, this can cause blindness.
- Radiation, e.g. radiation from radioactive sources can cause cancer.
- Fire, e.g. an unattended heater is a fire hazard.
- Electricity, e.g. faulty electrical equipment could give you a shock.

2) Then you'll need to suggest ways of reducing the risks involved with the hazard, e.g.:

- If you're working with springs, always wear safety goggles. This will reduce the risk of the spring hitting your eye if the spring snaps.
- If you're using a heater to raise the temperature of something, stand the apparatus on a heat proof mat. This will reduce the risk of starting a fire.

You can find out about potential hazards by looking in textbooks, doing some internet research, or asking your teacher.

You Could be Asked About Accuracy...

1) It's important that results are accurate. Accurate results are those that are really close to the true answer.
2) The accuracy of your results usually depends on your method.

E.g. say you wanted to estimate the volume of an irregularly shaped solid. Working out its volume by measuring the sides isn't very accurate because this will not take into account any gaps in the object. It's more accurate to measure the volume by submerging the object in a eureka can filled with water. You can then measure the volume of water displaced by the object to get its volume (see p.53).

3) To make sure your results are as accurate as possible, you need to make sure you're measuring the right thing and that you don't miss anything or include anything that shouldn't be included in the measurements.

E.g. if you're using a eureka can to measure the volume of an object, make sure the object is completely submerged in the water before measuring the volume of the displaced water, or the measured volume will be too small.

...And Precision

Results also need to be precise. Precise results are ones where the data is all really close to the mean (average) of your repeated results (i.e. not spread out).

Repeat	Data set 1	Data set 2
1	12	11
2	14	17
3	13	14
Mean	13	14

Data set 1 is more precise than data set 2.

Sometimes, results are described as precise if they've been taken using sensitive instruments that can measure in small increments, e.g. using a ruler with a millimetre scale gives more precise data than a ruler with a scale in centimetres.

Not revising — an unacceptable exam hazard...

It may interest you to know that you won't just have to write about other people's experiments in the exam. Sometimes you'll be asked to describe how you'd carry out your own experiment and all this stuff about reliability and what-not will apply then too. Ah. From the look on your face, I'm guessing it didn't interest you to know that.

Drawing Graphs and Interpreting Results

Processing your data means doing some calculations with it to make it more useful. Once you've done that, you can present your results in a nice chart or graph to help you spot any patterns in your data.

You Should Be Able to Identify Anomalous Results

1) Most results vary a bit, but any that are totally different are called anomalous results.
2) They're usually caused by human errors, e.g. by a mistake made when measuring or by not setting up a piece of equipment properly.
3) You could be asked to identify an anomalous result in the exam and suggest what caused it — just look for a result that doesn't fit in with the rest (e.g. it's too high or too low) then try to figure out what could have gone wrong with the experiment to have caused it.
4) If you're calculating an average, you should ignore any anomalous results.

You Might Have to Process Your Data

1) When you've done repeats of an experiment you should always calculate the mean (average). To do this add together your data values and divide by the number of repeats.
2) You might also need to calculate the range (how spread out the data is). To do this find the largest number and subtract the smallest number from it.

Ignore anomalous results when calculating these.

Example: The results of an experiment show the extension of two springs when a force is applied to both of them. Calculate the mean and range for the extension for both springs.

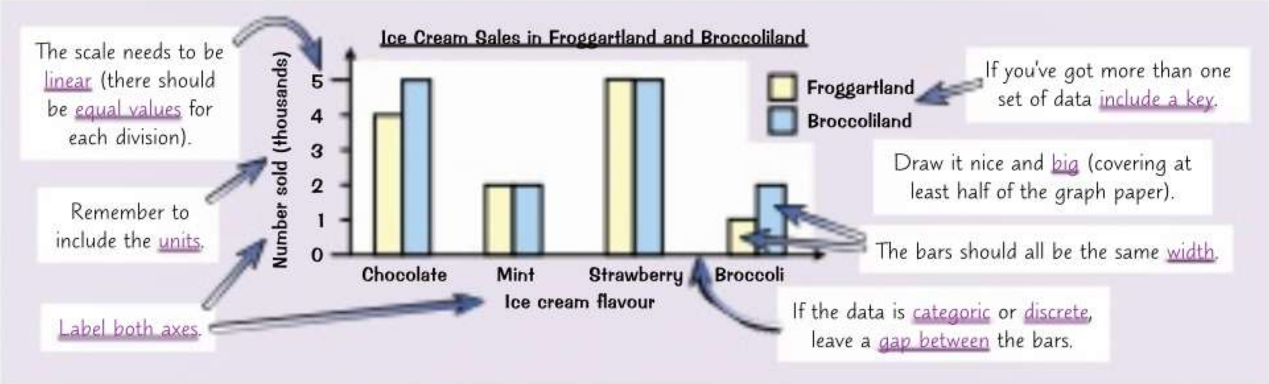
Spring	Repeat 1 (mm)	Repeat 2 (mm)	Repeat 3 (mm)	Mean (mm)	Range (mm)
A	28	37	31	(28 + 37 + 31) ÷ 3 = **32**	37 – 28 = **9**
B	47	52	60	(47 + 52 + 60) ÷ 3 = **53**	60 – 47 = **13**

Bar Charts can be Used to Show Different Types of Data

Bar charts can be used to display:

1) Categoric data — data that comes in distinct categories, e.g. solid, liquid, gas.
2) Discrete data — data that can be counted in chunks, where there's no in-between value, e.g. number of protons is discrete because you can't have half a proton.
3) Continuous data — numerical data that can have any value in a range, e.g. length, volume, temperature.

There are some golden rules you need to follow for drawing bar charts:



The scale needs to be linear (there should be equal values for each division).

Remember to include the units.

Label both axes.

If you've got more than one set of data include a key.

Draw it nice and big (covering at least half of the graph paper).

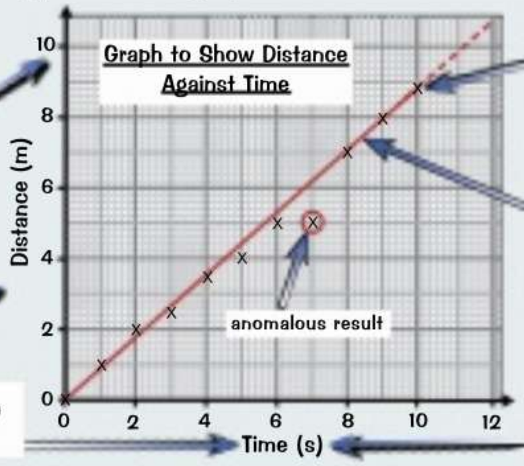
The bars should all be the same width.

If the data is categoric or discrete, leave a gap between the bars.

Graphs can be Used to Plot Continuous Data

If both variables are continuous you should use a graph to display the data.

Here are the rules for plotting points on a graph:



Use the biggest data values you've got to draw a sensible scale on your axes. Here, the longest distance is 8.8 m, so it makes sense to label the y-axis up to 10 m.

The dependent variable goes on the y-axis (the vertical one).

The independent variable goes on the x-axis (the horizontal one).

To plot points, use a sharp pencil and make neat little crosses (don't do blobs).

If you're asked to draw a line (or curve) of best fit, draw a line through or as near to as many points as possible, ignoring any anomalous results. Don't join the crosses up.

Draw it nice and big (covering at least two thirds of the graph paper).

Remember to include the units.

You Need to be Able to Interpret Graphs

1) A graph is used to show the relationship between two variables — you need to be able to look at a graph and describe this relationship.

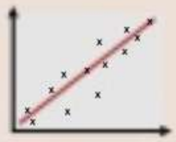
   E.g. the graph above shows that as time goes on, the distance increases and that the distance is directly proportional to time.

A relationship is directly proportional if one variable increases at the same rate as the other variable (so if one variable doubles, the other also doubles, etc.). A graph shows direct proportion when the line is straight and goes through the origin (0,0).

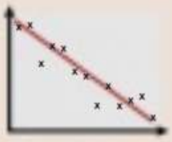
2) You also need to be able to read information off a graph. In this example, if you wanted to know the distance travelled after 8.2 s, you'd draw a vertical line up to the graph line from the x-axis at 8.2 s and a horizontal line across to the y-axis from the graph line. This would tell you that the distance travelled in 8.2 s was around 7.2 m.

Graphs Show the Correlation Between Two Variables

1) You can get three types of correlation (relationship) between variables:



POSITIVE correlation: as one variable increases the other increases.



INVERSE (negative) correlation: as one variable increases the other decreases.

NO correlation: no relationship between the two variables.

2) Just because there's correlation, it doesn't mean the change in one variable is causing the change in the other — there might be other factors involved.

3) There are three possible reasons for a correlation:

- CHANCE: It might seem strange, but two things can show a correlation purely due to chance.
- LINKED BY A 3RD VARIABLE: A lot of the time it may look as if a change in one variable is causing a change in the other, but it isn't — a third variable links the two things.
- CAUSE: Sometimes a change in one variable does cause a change in the other. You can only conclude that a correlation is due to cause when you've controlled all the variables that could, just could, be affecting the result.

I love eating apples — I call it core elation...

Science is all about finding relationships between things. And I don't mean that physicists gather together in corners to discuss whether or not Devini and Sebastian might be a couple... though they probably do that too.

Calculating Rates From Graphs

You can work out rates of change using graphs. I bet you can't wait to find out how...

Graphs Can Give You a Lot of Information About Your Data

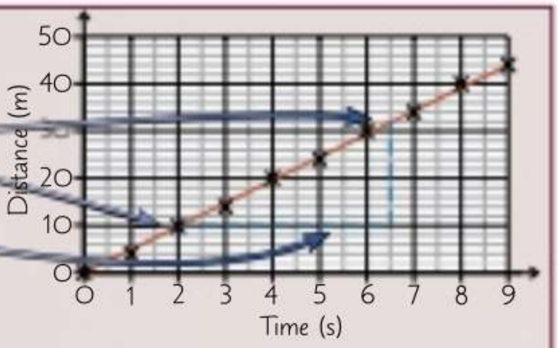
If you have a graph of distance against time, then the gradient (slope) of the graph will be equal to the speed — the steeper the slope, the faster the speed.

The gradient of a straight line is given by the equation: **gradient = change in y ÷ change in x**

Example: **The graph on the right shows the distance travelled by a vehicle against time. Calculate the vehicle's speed.**

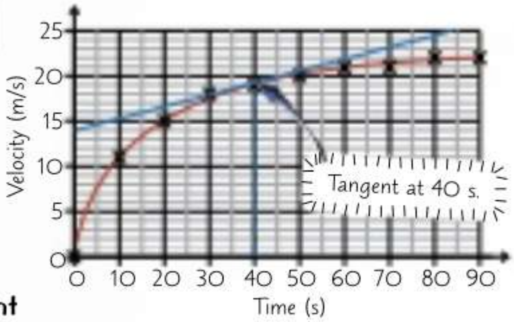
1) Find two points on the line that are easy to read the x and y values of (ones that pass through grid lines).
2) Draw a line straight down from the higher point and straight across from the lower one to make a triangle.
3) The height of your triangle = change in y
   The base of your triangle = change in x
   Change in y = 32 – 10 = 22   Change in x = 6.5 – 2 = 4.5
4) Use the formula to work out the gradient, and therefore the speed.
   Gradient = change in y ÷ change in x = 22 ÷ 4.5 = 4.9 m/s (to 2 s.f.)

The units of the gradient are (units of y)/(units of x).



You can use this method to calculate other rates from a graph, not just the rate of change of distance (which is speed).

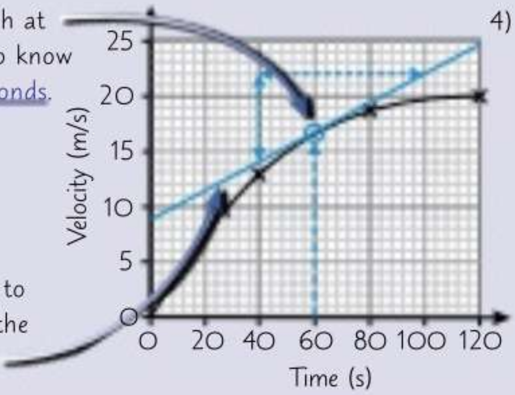
Draw a Tangent to Find the Gradient of a Curve



1) **If your graph (or part of it) is a curve, the gradient, and therefore rate, is different at different points along the curve.**
2) **To find the gradient of the graph at a certain point, you'll have to draw a tangent at that point.**
3) **A tangent is just a line that touches the curve and has the same gradient as the line at that point.**
4) **To draw a tangent, place a ruler on the line of best fit at the point you're interested in, so you can see the whole curve. Adjust the ruler so the space between the ruler and the curve is the same on both sides of the point. Draw a line along the ruler to make the tangent.**
5) **The rate at that point is then just the gradient of the tangent.**

Example: **The graph below shows the velocity of a vehicle, measured at regular intervals. What is the acceleration of the vehicle at 60 seconds?**

1) Position a ruler on the graph at the point where you want to know the rate — here it's 60 seconds.
2) Adjust the ruler until the space between the ruler and the curve is equal on both sides of the point.
3) Draw a line along the ruler to make the tangent. Extend the line right across the graph.



4) Pick two points on the line that are easy to read. Use them to calculate the gradient of the tangent in order to find the acceleration (see p.2):

gradient = change in y ÷ change in x
= (22 – 14) ÷ (100 – 40)
= 8 ÷ 60 = 0.13 m/s^2 (to 2 s.f.)

So, the acceleration of the vehicle at 60 seconds was 0.13 m/s^2.

I saw my physics teacher on holiday — he was a tanned gent...

Lots of nifty graph skills here. Gradients aren't too hard, but make sure those tangents don't trip you up.

Planning Experiments

In the exam, you could be asked to plan or describe how you'd carry out an experiment. The experiment might be one you've already come across (easy) or (gasp) you might be asked to come up with an experiment of your own to test something. I know. Examiners are harsh. It's not as bad as it sounds though.

Experiments Test Hypotheses

1) A hypothesis is a possible explanation for something that you've observed.
2) You can use experiments to test whether a hypothesis might be right or not. This involves making a prediction based on the hypothesis and testing it by gathering evidence (i.e. data) from investigations. If evidence from experiments backs up a prediction, you're a step closer to figuring out if the hypothesis is true.

You Need to Be Able to Plan a Good Experiment

Even if you can't remember all the details of an experimental method you've learned about, you could still get marks for describing things like the independent and dependent variables.

Here are some general tips on what to include when planning an experiment:

1) Say what you're measuring (i.e. what the dependent variable is going to be).
2) Say what you're changing (i.e. what the independent variable is going to be) and describe how you're going to change it.
3) Describe the method and the apparatus you'd use.
4) Describe what variables you're keeping constant — and how you're going to do it.
5) Say that you need to repeat the experiment at least three times, to make the results more reliable.
6) Say whether you're using a control or not.

Here's an idea of the sort of thing you might be asked in the exam and what you might write as an answer...

Exam-style Question:

1 Describe an experiment to investigate the effect of changing the angle of a ramp on the final speed of a toy car released at the top of it. (6 marks)

Example Answer:

In this experiment you should change the angle of the ramp. You can see what effect this has by measuring the average speed of the toy car on a flat section of track at the bottom of the ramp.

Measure the angle of the ramp with a protractor. Set up a flat runway at the bottom of the ramp, then put one light gate near the start of the runway and one light gate near the end of it. Measure the distance between the light gates with a ruler. Ensure the light gates are connected to a computer with data-logging software to record the time taken for the car to pass between them. Hold the car still at the top of the ramp, then let go so that it rolls down the ramp onto the runway. Record the time taken for the car to pass between the gates. Calculate the final speed of the car by dividing the distance between the gates by this time.

Carry out the experiment again with the ramp at different angles (e.g. 35°, 30°, 25° and 20°).

A line should be marked on the ramp to ensure the car is released from the same position each time. The same car should be used each time and the car should not be changed in any way. The same ramp and runway should be used each time.

Repeat the experiment three times for each angle of the ramp and calculate an average speed for each angle.

Plan your way to exam success...

The number of marks available for a question like this will vary, but it'll usually be around five or six. This means you'll have to write an extended answer. Think about what you're going to say beforehand and in what order — that way you're less likely to forget something important. Like what it is you're actually measuring, say.

Conclusions and Evaluations

Congratulations — you're nearly at the end of a gruelling investigation — time to draw conclusions and evaluate.

You Can Only Conclude What the Data Shows and NO MORE

1) Drawing conclusions might seem pretty straightforward — you just look at your data and say what pattern or relationship you see between the dependent and independent variables.

A Geiger-Müller counter is set up to measure the count rate a set distance away from a gamma radiation source (see p.68). The table shows the count rate before and after a sheet of paper is placed between the source and the counter:

Obstacle	Count rate in counts per second (cps)
None	15
Paper sheet	15

CONCLUSION: Gamma radiation is able to pass through a paper sheet.

2) But you've got to be really careful that your conclusion matches the data you've got and doesn't go any further.

You can't conclude that every type of radiation can pass through paper — the results might be completely different for other radiation types.

3) You also need to be able to use your results to justify your conclusion (i.e. back up your conclusion with some specific data).

The same amount of radiation passed through to the counter both before and after the paper was inserted, as the count rates were both the same at 15 cps.

4) When writing a conclusion you need to refer back to the original hypothesis and say whether the data supports it or not:

The hypothesis for this experiment might have been that gamma radiation can pass through a paper sheet. If so, the data supports the hypothesis.

Evaluations — Describe How it Could be Improved

An evaluation is a critical analysis of the whole investigation.

1) You should comment on the method — was it valid?
Did you control all the other variables to make it a fair test?
2) Comment on the quality of the results — was there enough evidence to reach a valid conclusion? Were the results reliable, valid, accurate and precise?
3) Were there any anomalous results? If there were none then say so.
If there were any, try to explain them — were they caused by errors in measurement?
Were there any other variables that could have affected the results?
4) All this analysis will allow you to say how confident you are that your conclusion is right.
5) Then you can suggest any changes to the method that would improve the quality of the results, so that you could have more confidence in your conclusion. For example, you might suggest changing the way you controlled a variable, or increasing the number of measurements you took. Taking more measurements at narrower intervals could give you a more accurate result. For example:

Springs stop returning to their original shape when they are stretched past their elastic limit. Say you do an experiment to find the elastic limit of a certain type of spring by taking measurements for applied forces of 1 N, 2 N, 3 N, 4 N and 5 N. The results of this experiment tell you that the elastic limit is at 4 N. You could then repeat the experiment with the same type of spring, taking more measurements around 4 N to get a more accurate value for the elastic limit.

6) You could also make more predictions based on your conclusion, then further experiments could be carried out to test them.

When suggesting improvements to the investigation, always make sure that you say why you think this would make the results better.

Evaluation — next time, I'll make sure I don't burn the lab down...

And that's a wrap. Well, not quite. You've still got the small matter of the whole exam shenanigans to look forward to. Around 20% of your marks will come from being able to describe experiments, and analysing and evaluating data and methods in an appropriate way — so, make sure you're happy with everything in this section. Best of luck.

Physics Formulas and Units

If formulas and units just look like a load of weird symbols and nonsense to you, then you're never going to get very far with Physics, that's for sure. They're the Physics alphabet and without them, you're... in trouble.

Formula Triangles

It's dead useful to learn how to put any formula into a triangle. There are two easy rules:

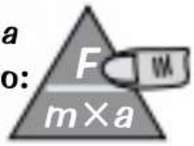
1) If the formula is "$A = B \times C$" then A goes on the top and $B \times C$ goes on the bottom.
2) If the formula is "$A = B/C$" then B must go on the top (because that's the only way it'll give "B divided by something") — and so pretty obviously A and C must go on the bottom.

Three Examples:

$V = I \times R$ turns into:

$p = F/A$ turns into:

$F = m \times a$ turns into:



How to use them: Cover up the thing you want to find and write down what's left showing.
EXAMPLE: To find a from the last one, cover up a and you get F/m left showing, so "$a = F/m$".

Some Awkward Formulas Don't Fit in Triangles

If you have a formula like: $v^2 = u^2 + 2as$... then there's no way it's going to fit in a formula triangle.

I'm afraid with these weirdy formulas, YOU JUST HAVE TO HANDLE THEM AS THEY ARE.

Units and Prefixes

1) You need to know a lot of units in Physics — things like metres (m) and watts (W). All the basic ones will be mentioned in the book.
2) But you need to know a few prefixes too. Prefixes go before units and make them 'bigger' or 'smaller' (like the 'c' in 'cm').
3) The most important prefixes are:

- 'k' means '× 1000' — e.g. 1 km = 1000 m
- 'M' means '× 1 000 000' — e.g. 1 MW = 1 000 000 W
- 'm' means '÷ 1000' — e.g. 1 mm = 0.001 m
- 'n' means '÷ 10^9' or '÷ 1 000 000 000' — e.g. 1 nm = 0.000000001 m

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