Speed and Velocity

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

Speed and **Velocity** are Both **How Fast** You're Going

1) 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°.

2) This means you can have objects travelling at a constant speed with a changing velocity.

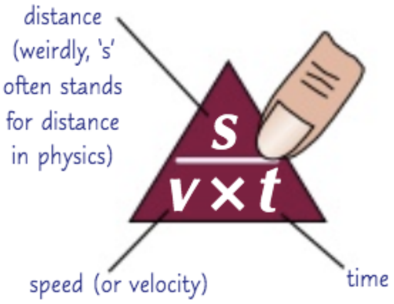
3) This happens when the object is changing direction whilst staying at the same speed.

Speed, **Distance** and **Time** — the **Formula**

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.

Answer: Using the formula triangle:
a) $v = s/t = 20/35 = 0.57$ m/s (to 2 d.p.)
b) $t = s/v = 75/0.57 = 132$ s = 2 min 12 s

Objects that are changing direction have a changing velocity...

...even if they're travelling at a steady speed. It's easy to get speed and velocity mixed up — they both tell you how fast something's going and even have the same units. So get the difference clear in your mind.

Acceleration

Acceleration is the rate of change of velocity. There are a couple of useful formulas for calculating acceleration on this page. Using them might take you a while at first, but over time you should get faster.

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.

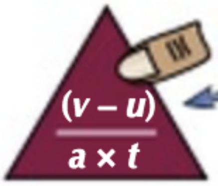
The formulas for acceleration on this page only work when the acceleration is constant (uniform).

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:

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



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

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

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.

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

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 $2.0\ m/s^2$ as it heads towards a built-up area 112 m away.
What will its speed be when it reaches the built-up area?

Answer:
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. $v = \sqrt{81} = 9\ m/s$

MATHS TIP

Make sure you're comfortable rearranging equations...

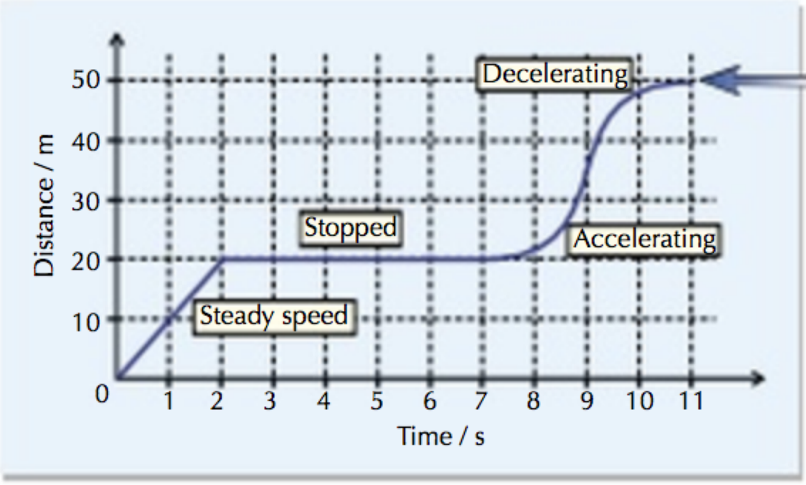
You'll need to be able to rearrange all types of formulas in your exam. Make sure you can deal with the ones that don't fit into a formula triangle (like $v^2 = u^2 + 2as$) as well as the ones that do.

Distance-Time Graphs

Distance-time (D-T) graphs tell you how fast an object is moving and how far it's travelled. Simple as that really. Make sure you get them straight in your head before turning over...

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

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



After 11 seconds, the object has travelled 50 m from its starting point.

1) The gradient (slope) at any point gives the speed of the object.

2) Flat sections are where it's stopped.

3) A steeper graph means it's going faster.

4) Curves represent acceleration.

5) A curve getting steeper means it's speeding up (increasing gradient).

6) A levelling off curve means it's slowing down (decreasing gradient).

Calculating Speed from a **Distance-Time Graph**

To calculate the speed from a distance-time graph, just work out the gradient:

In the above graph, the speed of the first section (between 0 and 2 s) is:

$$\text{Speed} = \text{gradient} = \frac{\text{vertical}}{\text{horizontal}} = \frac{20}{2} = 10\ \text{m/s}$$

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 50 ÷ 11 = 4.5 m/s (to 2 s.f.)

EXAM TIP

Read the axes of any graph you get given carefully...

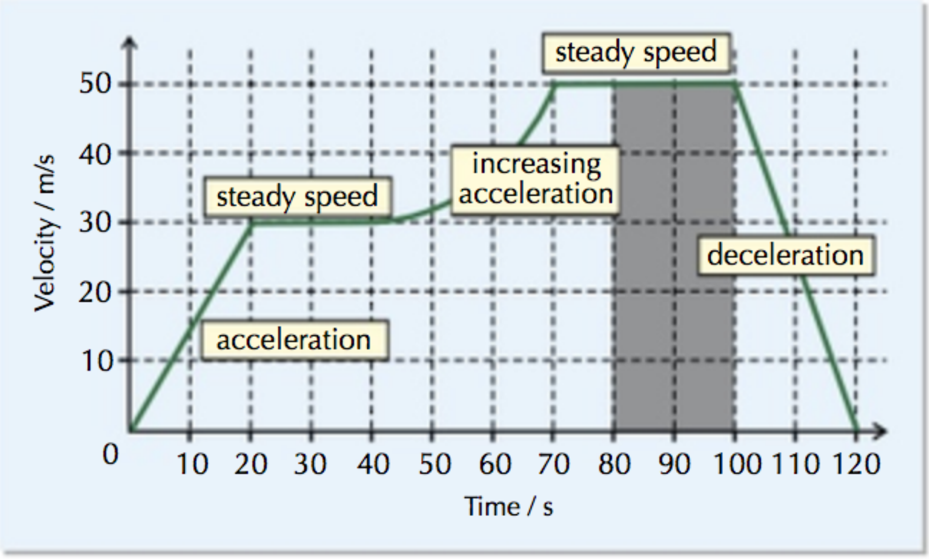
Make sure you don't get confused between distance-time graphs and velocity-time graphs (which are coming up next). They do look quite similar, but they tell you different things...

Velocity-Time Graphs

Velocity-time (V-T) graphs show you how the velocity of an object changes over time. Simple as that really.

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.



1) Gradient = acceleration.

2) Flat sections represent steady speed.

3) The steeper the graph, the greater the acceleration or deceleration.

4) Uphill sections (/) are acceleration.

5) Downhill sections (\) are deceleration.

6) The area under any part of the graph is equal to the distance travelled in that time interval.

7) A curve means changing acceleration.

Finding Acceleration, Speed or Distance from a V-T Graph

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 50 m/s × 20 s = 1000 m

Mass, Weight and Gravity

It might seem a bit odd, but it's true — mass and weight are not the same thing.
The difference between them is all thanks to the force of gravity...

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 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/s^2 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 145).

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 very easy to use:

Example: What is the weight, in newtons, of a 5 kg mass, both on Earth and on the Moon?
Answer: Use the formula $W = m \times g$.
On Earth: $W = 5 \times 10 = 50$ N (The weight of the 5 kg mass is 50 N.)
On the Moon: $W = 5 \times 1.6 = 8$ N (The weight of the 5 kg mass is 8 N.)

Weight is dependent on gravity — mass is not...

In everyday life, people tend to talk about their body "weight" in kg — but that's actually their body mass.

Warm-Up & Exam Questions

It's time to take a break and check how much of the information on the previous few pages has gone in. The warm-up questions will help get those brain cogs up to speed before you tackle the exam questions.

Warm-Up Questions

1) How are speed and velocity different?
2) Samuel runs 125 metres at an average speed of 6.50 m/s. How long does this take Samuel?
3) What are the units of acceleration?
4) What is represented by the gradient of a velocity-time graph?
5) What are the units of mass? And of weight?

Exam Questions

1 A cyclist travels 1500 m from his house to his local shops in 300 seconds.

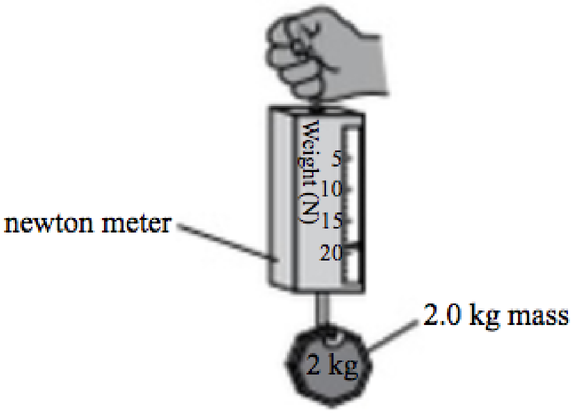
(a) Calculate the cyclist's average speed in m/s during his journey.

[2 marks]

(b) On the return home, the cyclist accelerates from 2.0 m/s with a steady acceleration of 2.4 m/s^2. Calculate the time in seconds that it takes the cyclist to reach a speed of 10 m/s.

[3 marks]

2 A student is measuring gravitational field strength, *g*, in a classroom experiment. He takes an object with a mass of 2.0 kg and suspends it from a newton meter held in his hand. He takes multiple readings of the object's weight and calculates an average value of 19.6 N.



(a) (i) State the equation linking weight, mass and gravitational field strength.

[1 mark]

(ii) Calculate the gravitational field strength in the student's classroom and give the unit.

[3 marks]

(b) The Moon's gravity is weaker than the Earth's. State how the student's measurement of the object's weight would differ if he performed the same experiment on the Moon. Explain your answer.

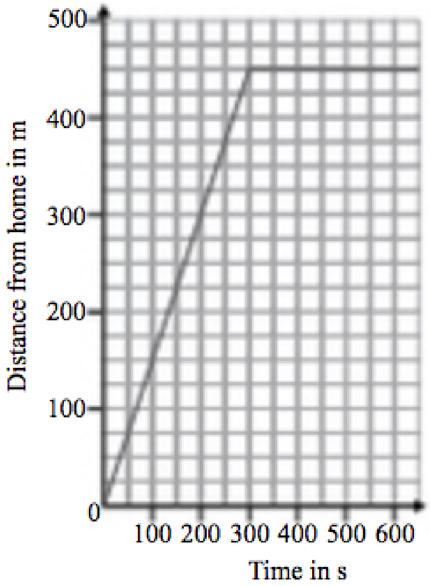
[2 marks]

Exam Questions

3 A tractor ploughing a field accelerates at 2 m/s^2 for 10 metres, after which its speed is 7 m/s. Calculate the tractor's speed in m/s before it started accelerating.

[3 marks]

4 A student walked from her home to a sports centre for a football training session. Below is a distance-time graph for her journey.



(a) Use the graph to find the time in seconds that it took for the student to reach the sports centre.

[1 mark]

(b) State whether the student walked to the sports centre at a steady speed. Explain how you know.

[2 marks]

(c) Use the graph to calculate the student's average speed in m/s as she walked to the sports centre.

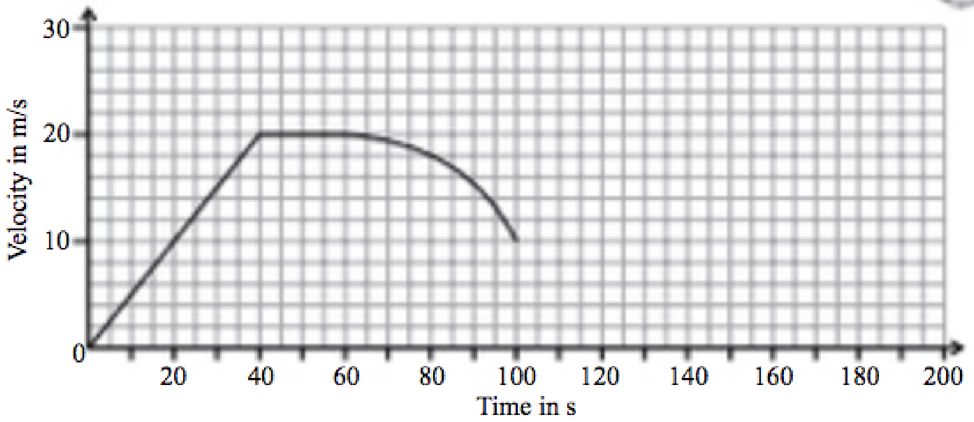
[3 marks]

(d) The student returns home in a car after training. During the journey, the car constantly accelerates for 10 s to overtake another vehicle and then travels at a constant speed for a further 30 s.

Sketch a velocity-time graph to show the motion of the car during this time.

[3 marks]

5 The diagram shows a velocity-time graph for a car during a section of a journey.



(a) Describe the motion of the car between 60 and 100 seconds.

[2 marks]

(b) Calculate the distance travelled by the car in metres between 40 and 60 seconds.

[3 marks]

(c) Calculate the acceleration of the car in m/s between 0 and 40 seconds.

[3 marks]

(d) After 100 seconds, the car accelerates steadily for 40 seconds until it reaches a steady velocity of 30 m/s, which it maintains for 60 seconds. Copy and complete the graph to show this motion.

[2 marks]

Forces

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:

1) Gravity or weight (see page 5) — close to a planet this acts straight downwards.

2) Reaction force — acts perpendicular to a surface and away from it (so if the surface is horizontal, the reaction force acts straight upwards).

3) Electrostatic force between two charged objects. The direction depends on the type of the charge (like charges repel, opposite charges attract) — see page 45.

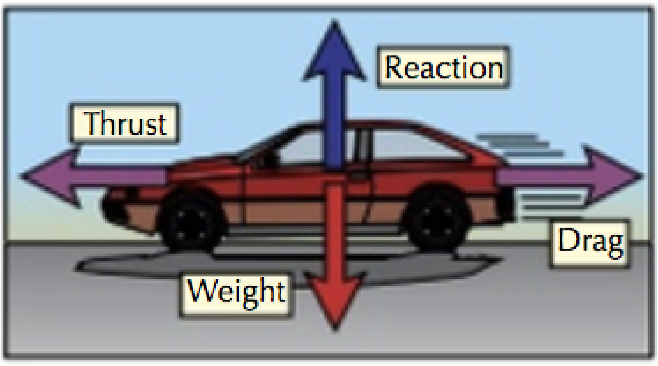
4) Thrust — e.g. push or pull due to an engine or rocket speeding something up.

5) Drag or air resistance or friction which is slowing the thing down.

6) Lift — e.g. due to an aeroplane wing.

7) 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.

REVISION TIP

All forces are just a push or a pull

Learn all of the different types of force listed above, and make sure you understand what they mean. You can test yourself by trying to come up with examples of each type of force in action.

Friction

Friction is found nearly everywhere, slowing down and stopping moving objects.

Friction is Always There to Slow Things Down

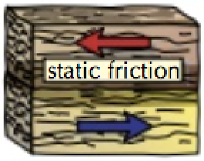
1) If an object has no force propelling it along, it will always slow down and stop because of friction (unless you're in space where there's no friction). Friction is a force that opposes motion.

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**

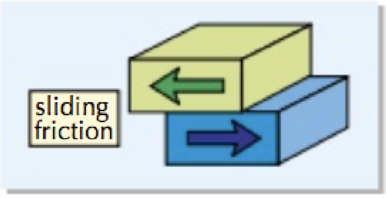
This is known as static friction.



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

This is known as sliding friction.

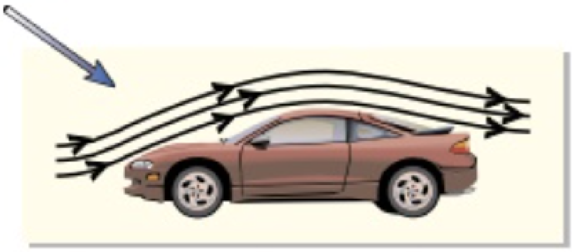
You can reduce both these types of friction by putting a lubricant like oil or grease between the surfaces. Friction between solids can often cause wear of the two surfaces in contact.



c) **Resistance** or **"Drag"** from **Fluids** (Liquids or Gases, e.g. Air)

1) 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.



2) For a given thrust, the higher the drag, the lower the top speed of the car.
3) 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.
4) In a fluid, friction always increases as the speed increases — see page 16.

Motion is always opposed by friction (unless you're in a vacuum)

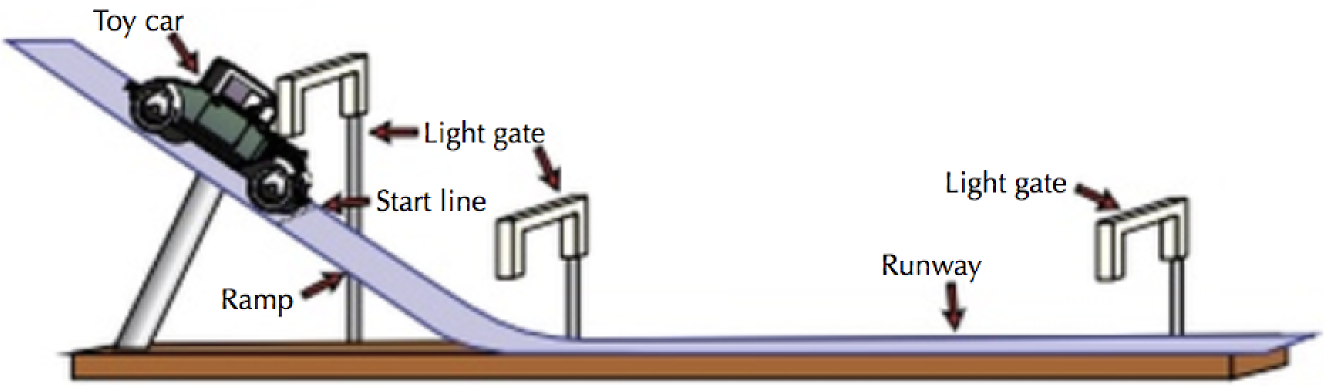
You can't move without counteracting friction. But it can be useful, e.g. if you need to slow something down.

PRACTICAL

Investigating Motion

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 (see 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 more streamlined cars to go quicker — see p.9.

PRACTICAL TIP

Only change the independent variable...

...e.g. if you're investigating the effect of the angle of the slope on the car's motion, make sure that's the only thing that changes. Control the other variables (like the distance travelled along the ramp).

Warm-Up & Exam Questions

OK, questions can be a drag — but they'll really help you see how much you've taken in, so go on...

Warm-Up Questions

1) Give the name of the force that pulls objects towards the centre of the Earth.
2) What are electrostatic forces?
3) What is static friction?
4) Suggest how putting bikes on the roof of a car would affect its top speed.

Exam Questions

1 The diagram below shows a truck moving forwards at a steady speed.
The thrust (driving force) acting on the truck is shown.

(a) (i) As the truck moves, it experiences resistance from drag and friction.
State the direction in which the resistance acts.

[1 mark]

(ii) Describe how the speed of the truck affects the resistance force it experiences.

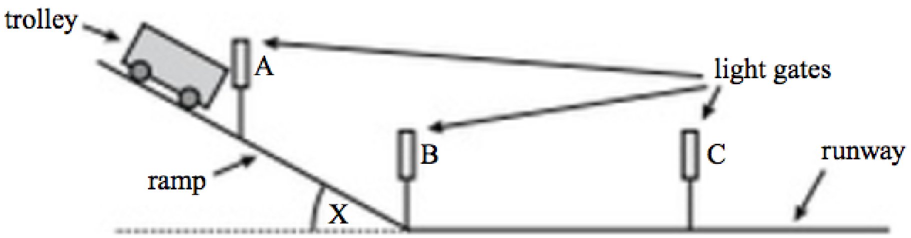
[1 mark]

(b) Name **one** more force that acts on the truck and state the direction in which it acts.

[2 marks]

PRACTICAL

2 A student wants to carry out an experiment to investigate the motion of a trolley down a ramp.
His textbook suggests setting up his apparatus as shown in the diagram.



(a) Describe how he could use this apparatus to find the acceleration of the trolley down the ramp.

[6 marks]

(b) The student decides to investigate how the distance the trolley travels down the ramp and the angle of the ramp (X) affect the trolley's speed at the bottom of the ramp.
He changes both the angle of the ramp and the distance of the trolley along the ramp each time he repeats the experiment. He uses light gates to measure the trolley's speed at the bottom.
The student concludes that as the angle of the ramp decreases, the speed of the trolley increases.
Explain why he cannot conclude this from his data and suggest how he could improve his method.

[3 marks]

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 — Scalars 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 previous page). 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:

In diagrams, vector quantities are usually represented by arrows.

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

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

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

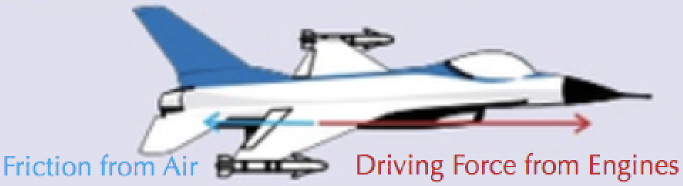
To Work Out Resultant Force You Need To Combine Vectors

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

Answer: 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: The jets on a plane are producing a thrust of 22 000 N east, and the friction from the air is 8000 N west at this speed.



a) What is the resultant force acting on the plane?
b) Find the acceleration of the plane in part a) if it has a mass of 10 000 kg.

Answer: a) Draw the vectors end to end:

b) Rearrange $F = ma$ to give:
$a = F \div m = 14\ 000 \div 10\ 000 = 1.4\ \text{m/s}^2$

The resultant force — one force with the same result as many

You'll most often encounter a resultant force as the difference between some kind of driving force and a resistive force, acting in opposite directions along the same line. For example, driving force and friction.

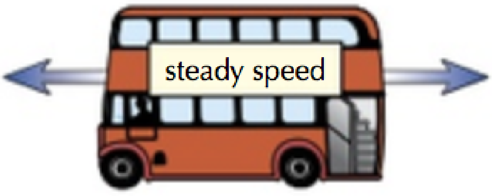
The Three Laws of Motion

In the 1660s, a chap called Isaac Newton worked out three laws of motion. Here are the first two.

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.

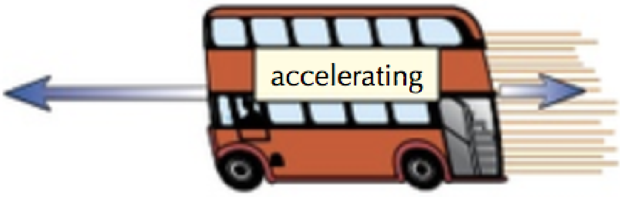
1) When a train or car or bus or anything else is moving at a constant velocity then the forces on it must be balanced.
2) Never let yourself entertain the idea that things need a constant overall force to keep them moving.
3) To keep going at a steady speed, there must be zero resultant force — and 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.
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". You get steady speed from balanced forces. If there's an overall force it will always accelerate.

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.

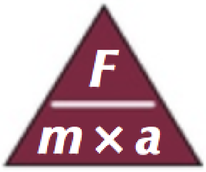
In a nutshell, any resultant force will produce acceleration, and this is the formula for it:

Force = mass × acceleration

$$F = ma$$

m = mass a = acceleration

F is always the resultant force



The Three Laws of Motion

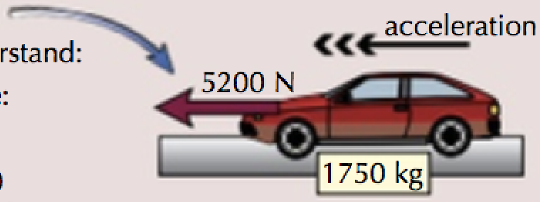
You can use Newton's second law to find an object's acceleration. All you need to know is the object's mass and the resultant force acting on it. You might have to rearrange the equation first though...

Resultant Force is Really Important — Especially for "***F = ma***"

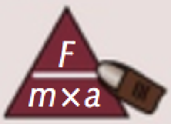
1) The notion of resultant force is a really important one for you to get your head round. It's not especially tricky — it's just that it seems to get kind of ignored.
2) In most real situations there are at least two forces acting on an object along any direction. The overall effect of these forces 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.

Answer: First draw a force diagram for the car — this will make the situation easier to understand:



Apply "$F = ma$" using the formula triangle:



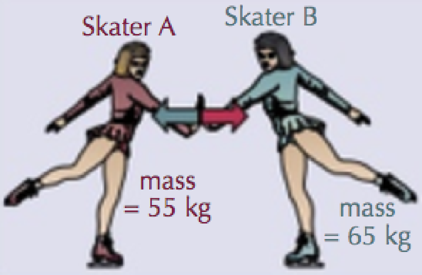
$$a = F/m$$
$$= 5200 \div 1750$$
$$= 3.0\ \text{m/s}^2\ \text{(2 s.f.)}$$

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.
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.

Warm-Up & Exam Questions

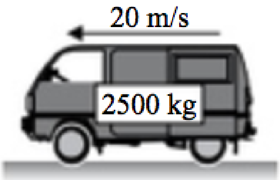
I won't force you to do these questions, but there's no better way for you to prepare for your exams...

Warm-Up Questions

1) What is Newton's first law of motion?
2) If two forces are acting in the same direction, how do you find the resultant force?
3) State whether each of the following is a scalar or vector quantity:
   a) mass b) velocity c) force d) time

Exam Questions

1 A camper van has a mass of 2500 kg. It is being driven along a straight, level road at a constant speed of 20 m/s.



(a) A wind blows straight at the front of the van with a force of 200 N, causing it to slow down. Calculate the van's deceleration in m/s^2.

[2 marks]

(b) The van begins travelling at a steady speed before colliding with a stationary traffic cone that has a mass of 10 kg. The traffic cone accelerates at 29 m/s^2 in the direction of the van's motion.

(i) Calculate the force in N applied to the traffic cone by the van.

[2 marks]

PAPER 2

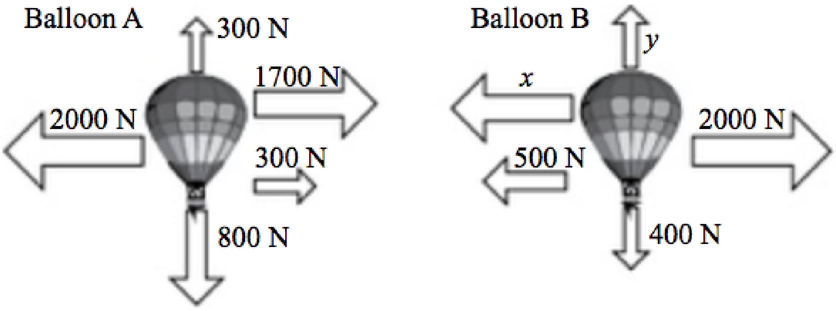
(ii) State the size of the force in N applied by the cone to the van during the collision.

[1 mark]

(iii) Calculate the deceleration of the van in m/s^2 during the collision.
Assume all of the force applied by the cone to the van causes the deceleration.

[2 marks]

2 The figure below shows two hot air balloons, labelled with the forces acting on them.



(a) Calculate the resultant force in N acting on balloon A.

[2 marks]

(b) The resultant force acting on balloon B is zero.

(i) Calculate the size of force y in N.

[1 mark]

(ii) Calculate the size of force x in N.

[1 mark]

Terminal Velocity

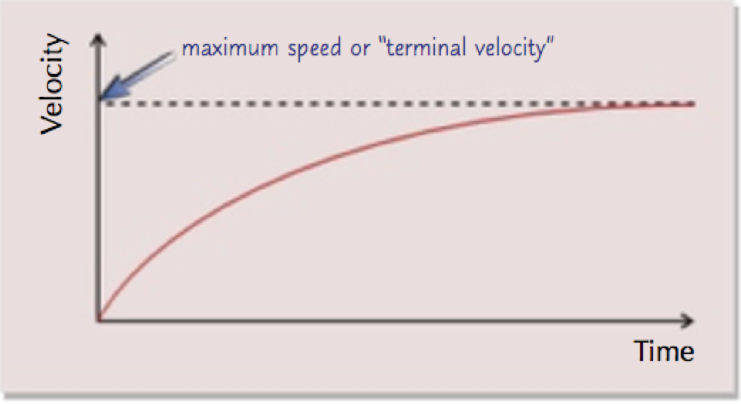
If an object falls for long enough before it hits the ground, it will reach its maximum, or terminal, velocity.

Moving Objects Can Reach a Terminal Velocity

This whole terminal velocity thing is explained by Newton's laws of motion (see page 12).

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.
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.

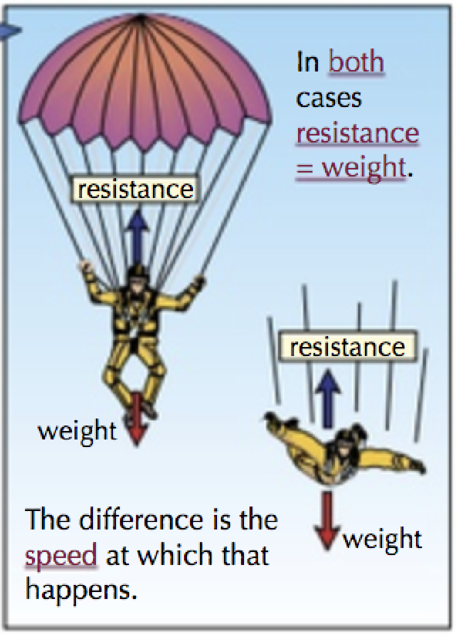


It's a bit like when you (very carefully) put your hand out of the window of a car as it moves along. At low speeds, you hardly notice the air pushing against your hand. But as the car goes faster, the air pushes your hand backwards much harder.

Shape and Area Affect the Terminal Velocity of Falling Objects

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, a hammer and a feather 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.
- Without his parachute open he has quite a small area and a force equal to his weight pulling him down.
- He reaches a terminal velocity of about 120 mph.
- But with the parachute open, there's much more air resistance (at any given speed) and still only the same force pulling him down.
- 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 resistance = weight.

The difference is the speed at which that happens.

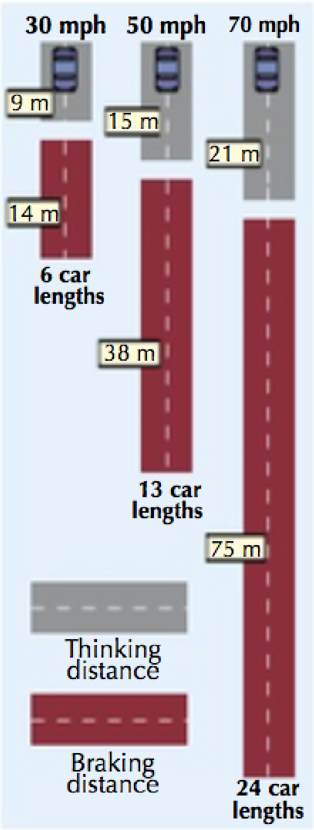
Stopping Distances

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 lots of other factors involved...

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 in exam questions, so make sure you learn it.)
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



The figures above for typical stopping distances are from the Highway Code.

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 — 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 towing a caravan.

c) How good the brakes are — brakes must be checked and maintained regularly. Worn or faulty brakes may 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.

Warm-Up & Exam Questions

Don't stop now — tackle these questions, then go on to the next section while you've got the momentum.

Warm-Up Questions

1) When does a falling object reach terminal velocity?
2) Explain why a car takes longer to stop when it's full of passengers.
   State two additional factors that increase stopping distance.
3) What does "conservation of momentum" mean?

Exam Questions

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. Grade 4-6

(a) (i) What name is given to the distance travelled by a car between the driver first spotting a hazard and the driver applying the brakes?

[1 mark]

(ii) Give **two** factors that can affect this distance.

[2 marks]

(b) (i) What is meant by the **braking distance** of a car?

[1 mark]

(ii) Give **two** factors that can affect this distance.

[2 marks]

2 A person is driving a car in heavy rain. Grade 4-6

(a) State and explain **one** way in which heavy rain can increase a car's stopping distance.

[2 marks]

(b) Suggest **one** way a driver can decrease their stopping distance if driving in heavy rain.

[1 mark]

(c) The driver sees a deer and stops the car. The car covers a distance of 37 m between the driver spotting the deer and the car coming to a stop. The braking distance of the car is 28 m. Calculate the thinking distance covered by the car in m.

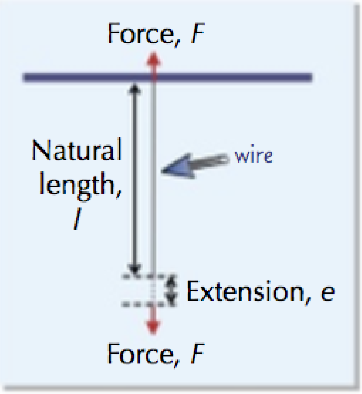
[2 marks]

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**

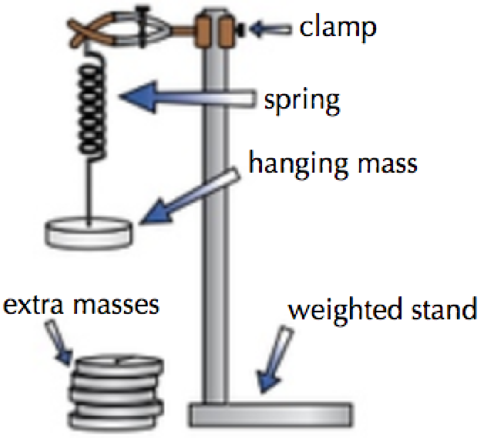
1) The length of an unstretched metal wire is called its natural length, *l*.
2) If a metal wire (see right) is supported at the top and then a weight attached to the bottom, it stretches. The weight pulls down with force *F*, producing an equal and opposite force at the support.
3) This will also happen 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 below. Make sure you have plenty of extra masses, and measure the weight of each (with a balance).

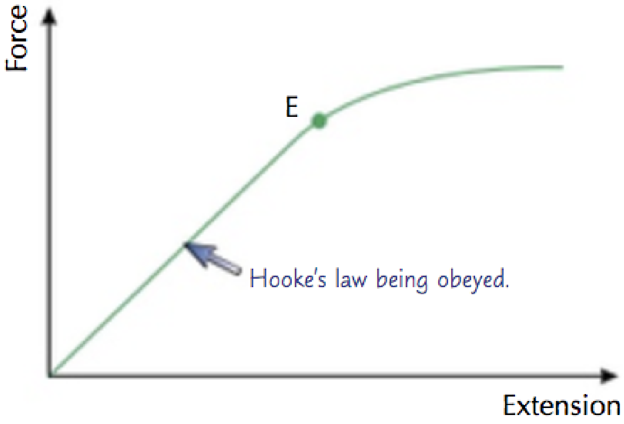


2) Measure the length of the spring (e.g. with an accurate mm ruler) when no load is applied. Ensure the ruler is vertical (e.g. with a set square) and measure the spring at eye level. (This is the spring's natural length.)
3) Add one mass at a time and allow the spring to come to rest, then measure 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

If you stretch a spring too far, Hooke's law won't apply and it won't go back to its original shape.

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 above 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.

If the force-extension graph is linear, Hooke's law holds true...

...and this means that the deformation is elastic (so you know that the deformed material can return to its original shape from that amount of extension). As soon as the graph starts to curve, you know that the material has been stretched past its elastic limit — so it will no longer spring back into its original shape.

Warm-Up & Exam Questions

Time for questions — the warm-up ones will ease you in, but the exam ones should stretch you...

Warm-Up Questions

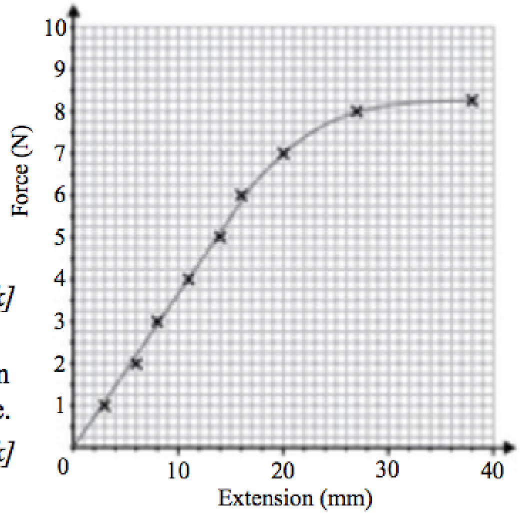
1) Briefly describe how you could find the centre of gravity of an irregular flat shape.
2) True or false? The shorter the perpendicular distance between the line of action of a force and the pivot, the greater the moment of the force.
3) What does it mean if a material displays "elastic behaviour"?

Exam Questions

1 A student investigates how a spring extends when a force is applied to it.

Grade 4-6

His results are shown in the graph to the right.



(a) Describe the relationship between force and extension up to a force of 5 N.

[1 mark]

(b) An identical spring is pulled with a force of 7.5 N. The elastic limit of the spring is 7.2 N. State and explain whether or not the spring will return to its original shape.

[1 mark]

PAPER 2

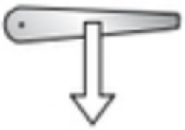
2 A door has a horizontal door handle. To open the door, its handle needs to be rotated clockwise. Pictures A, B, C and D show equal forces being exerted on the handle. State which picture shows the largest moment on the handle. Explain your answer.

Grade 6-7

A

B

C



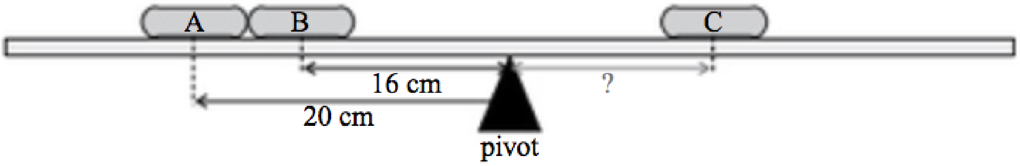
D

[2 marks]

PAPER 2

3 The diagram shows three weights on a light plank, resting on a pivot. Weight A is 2 N and sits 20 cm to the left of the pivot. Weight B exerts an anticlockwise moment of 0.8 Nm.

Grade 7-9



(a) Calculate the anticlockwise moment in Nm exerted by weight A.

[3 marks]

(b) The system is currently balanced. Weight C has a weight of 8 N. Calculate the distance of weight C from the pivot in metres.

[4 marks]

Revision Questions for Section 1

That was a wild ride through forces and motion but thankfully that's all for Section 1. Time to test yourself.

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

Speed, Distance and Time (p.1-4) ☑

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? ☑

Mass, Weight and Gravity (p.5) ☑

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? ☑

Forces (p.8-10) ☑

10) In what direction does friction always act? ☑
11) Describe a simple experiment you could carry out to investigate the motion of a toy car. ☑

Newton's Laws of Motion and Combining Forces (p.12-14) ☑

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) What is Newton's third law of motion? ☑
15) What's the difference between a vector quantity and a scalar quantity? ☑
16) *What's the resultant force on a train with a driving force of 19 000 N and a drag of 13 500 N? ☑

Terminal Velocity, Stopping Distances and Momentum (p.16-19) ☑

17) Why does a falling object reach a terminal velocity? ☑
18) Which two distances do you add to find the stopping distance of a car? ☑
19) What's the relationship between momentum, mass and velocity? ☑
20) *What's the mass of a car that has a momentum of 14 700 kg m/s when moving at 15 m/s? ☑
21) *A car's brakes apply a force of 230 N for 10 seconds. Find its change in momentum. ☑
22) How do airbags in cars reduce the risk of injury to the passengers in a crash? ☑

Turning Forces, Moments and Hooke's Law (p.22-26) ☑

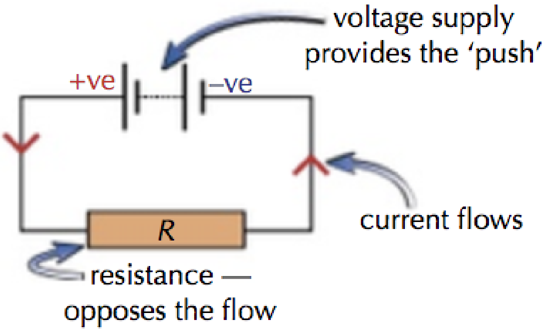
23) *Find the moment produced by a 5 N force acting at a perpendicular distance of 1.3 m from a pivot. ☑
24) What name is given to the point through which all of an object's weight acts? ☑
25) *A light rod is hung from two cables, one at each end. The rod is 1 m long. A mass is placed on the rod 25 cm from the left-hand end. Which cable will provide the largest supporting force? ☑
26) Describe a simple experiment you could use to investigate Hooke's law using a metal wire. ☑

*Answers on page 206.

Circuits — The Basics

Electricity's a pretty important topic in Physics. First up, some definitions and symbols to learn...

The Properties of a Circuit



Current

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. Current is measured in amperes, A.

Or 'amps' for short.

Voltage

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.). Voltage is measured in volts, V.

Resistance

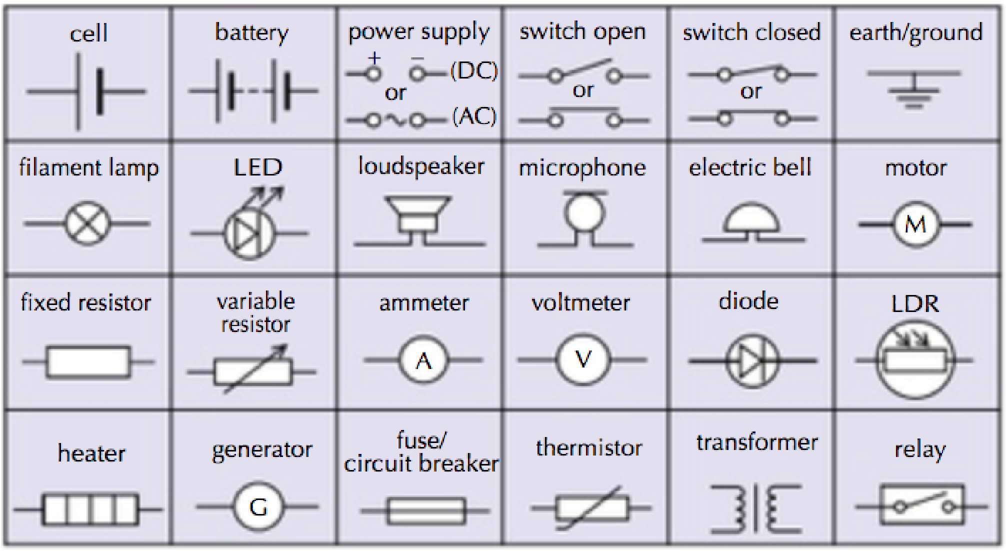
Resistance is anything in the circuit which slows the flow down. If you add more components to the circuit (one after the other) there will be a higher overall resistance. Resistance is measured in ohms, Ω.

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).

Circuit Symbols You Should Know:

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

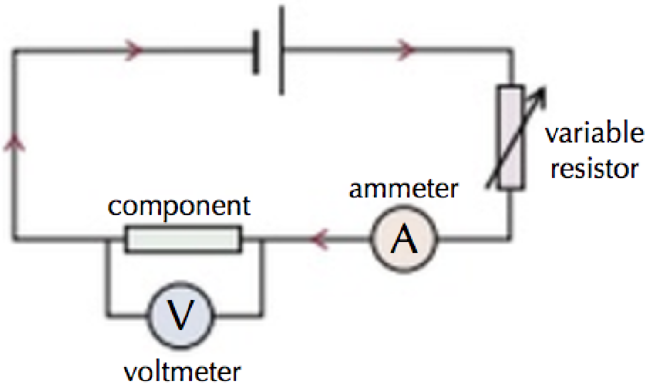


Circuits — The Basics

The standard test circuit is really useful — you can use it to find the current that's flowing through a component in a circuit, as well as the voltage that's across it.

The Standard Test Circuit

This is without doubt the most basic test circuit the world has ever known:



The Ammeter

1) Measures the current (in amps) flowing through the component.
2) Must be placed in series (see page 36) 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 37) around the component under test — not around the variable resistor or the battery.

Five Important Points:

1) This circuit is used for testing components.
2) The component, the ammeter and the variable resistor are all in series, which means that they can be put in any order in the main circuit.
3) The voltmeter, on the other hand, can only be placed in parallel around the component under test, as shown.
4) As you alter the resistance of the variable resistor, the current flowing through the component changes.
5) You can take several pairs of readings from the ammeter and voltmeter to see how the voltage changes as the current changes. You can plot these values for current and voltage on an *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 is used to measure current and voltage

If you build a standard test circuit (like the one above) and take readings from the ammeter and voltmeter, you can watch how the voltage across a component changes as you alter the current flowing through it.

Resistance and $V = I \times R$

The voltage across a component and the current flowing through it 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

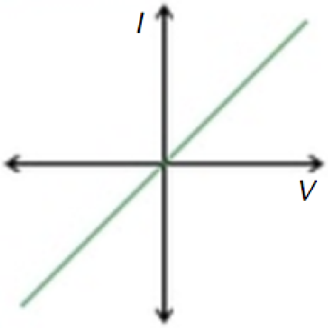
Example: A 4 Ω resistor in a circuit has a voltage of 6 V across it. What is the current through the resistor?

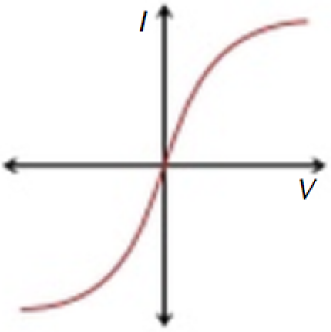
Answer: Use the formula $V = I \times R$.
You need to find I, so the version you need is $I = V/R$.
$I = 6 \div 4 = 1.5$ A

***I-V* Graphs** Show How Changing **Voltage** Affects **Current**

1) If you have pairs of current and voltage readings for a component, you can use them to plot a graph of current against voltage — also known as an *I-V* graph.

For a straight-line graph, the gradient is constant and equal to 1 ÷ resistance (because $R = V \div I$).





If the graph curves, it means the resistance is changing.

2) You work out the resistance for any pair of values (V, I) from an *I-V* graph by sticking them in the formula $R = V \div I$.

EXAM TIP

You could be asked to interpret an *I-V* graph...

Make sure you take care when reading values off any graph. Pay close attention to the axes, and make sure you've converted the values to the correct units before you do any calculations.

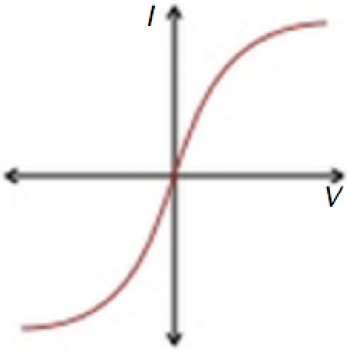
Resistance and $V = I \times R$

Current-voltage graphs look different for different circuit components.

Four Really Important Current-Voltage Graphs

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

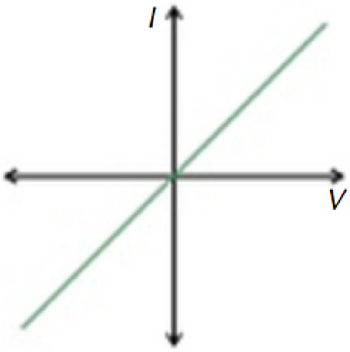
Metal Filament Lamp



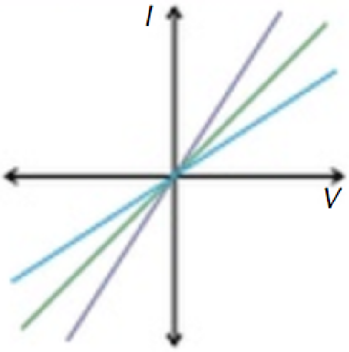
As the temperature of the metal filament increases, the resistance increases, hence the curve.

Wire

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



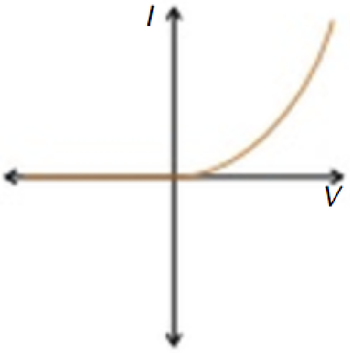
Different Resistors



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

Diode

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



LEDs, LDRs and Thermistors

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

Light-Emitting Diodes are Really Useful

1) Light-emitting diodes (LEDs) emit light when a current flows through them in the forward direction.

2) LEDs have lots of practical applications. 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.

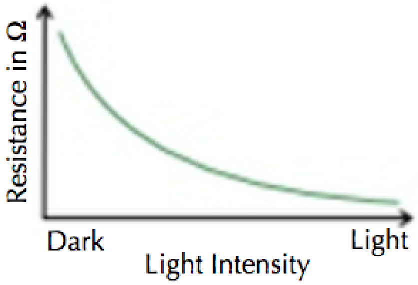
Some Components Can Change Resistance

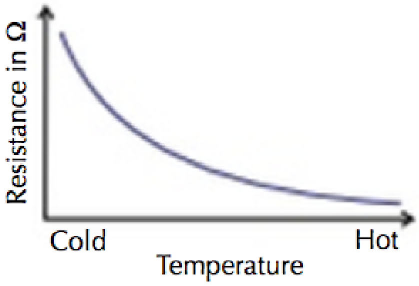
1) A light-dependent resistor (LDR) is a special type of resistor that changes its resistance depending on how much light falls on it.

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.

circuit symbol for an LDR





1) A thermistor is a temperature-dependent resistor.

2) In hot conditions, the resistance drops and in cool conditions, the resistance goes up.

circuit symbol for a thermistor

3) Thermistors make useful temperature detectors, e.g. car engine temperature sensors, thermostats and fire alarms.

Thermistors and LDRs have many applications...

...and they're not just limited to the examples on this page. For example, LDRs are used in digital cameras to control how long the shutter should stay open for. If the light level is low, changes in the resistance cause the shutter to stay open for longer than if the light level was higher. How interesting...

Warm-Up & Exam Questions

Phew — circuits aren't the easiest things in the world, are they? Make sure you've understood the last few pages by trying these questions. If you get stuck, just go back and re-read the relevant page.

Warm-Up Questions

1) How does the current in a circuit change if you increase the voltage?
2) True or False? If the resistance of a circuit increases, more current will flow.
3) A 6 Ω resistor in a circuit has a current of 1.5 A flowing through it. What is the voltage across the resistor?
4) Describe how the resistance of a thermistor varies with temperature.

Exam Questions

1 This question is about electricity supplies.

(a) Which describes the UK mains electricity supply?

☐ **A** 230 V a.c.

☐ **B** 320 V a.c.

☐ **C** 230 V d.c.

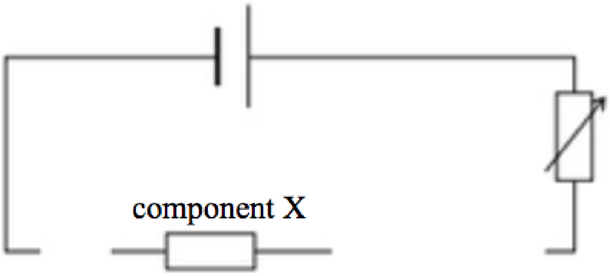
☐ **D** 320 V d.c.

[1 mark]

(b) Cells and batteries provide a d.c. supply. State what d.c. stands for and explain what it means.

[2 marks]

2 A student wants to produce a graph of current against voltage for component X. An incomplete diagram of the circuit he is going to use is shown below.



(a) Copy the circuit diagram and complete it by adding an ammeter and a voltmeter.

[2 marks]

(b) The student increases the resistance of the variable resistor while keeping the voltage of the power supply the same. State what will happen to the current in the circuit.

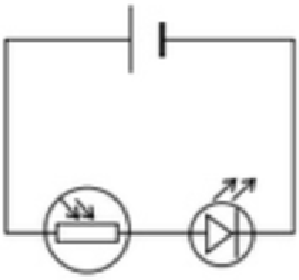
[1 mark]

(c) Outline a method that the student could use to obtain a set of data to produce his graph from.

[3 marks]

Exam Questions

3 The diagram to the right shows a circuit that contains an LED, a light-dependent resistor and a cell.



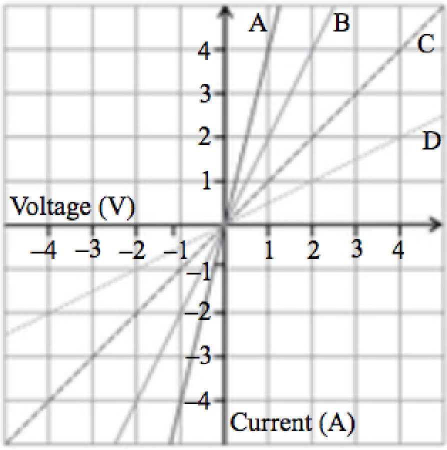
(a) Describe how you could tell that a current is flowing in the circuit.

[1 mark]

(b) The circuit is placed in a well lit room.
At the end of the day, the lights in the room are turned off.
State and explain how the resistance of the circuit changes when the room lights are switched off.

[2 marks]

4 The graph on the right shows current-voltage (I-V) graphs for four resistors at a constant temperature.



(a) State which resistor has the highest resistance.

[1 mark]

(b) (i) State the equation linking voltage, current and resistance.

[1 mark]

(ii) Calculate the resistance of resistor B. Give your answer in ohms.

[3 marks]

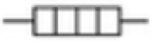
(iii) The resistance of resistor B is tested at different temperatures. At 30 °C, it has a resistance of 0.75 Ω when the voltage across it is 15 V. Calculate the current through the resistor at 30 °C. Give you answer in amps.

[3 marks]

5 This question is about circuit components.

(a) (i) Which circuit symbol below represents a fuse?

☐ **A** 

☐ **B** 

☐ **C** 

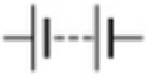
☐ **D** 

[1 mark]

(ii) Which circuit symbol below does **not** represent a type of power source?

☐ **A** 

☐ **B** 

☐ **C** 

☐ **D** 

[1 mark]

(b) (i) Draw a circuit diagram to represent a circuit in which the brightness of a lamp depends on temperature. The circuit should contain **three** components.

[3 marks]

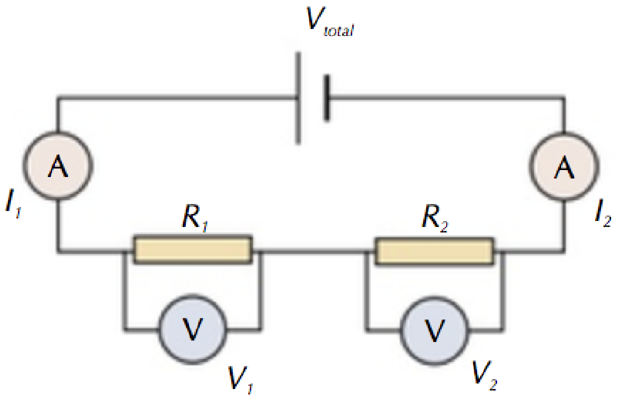
(ii) Describe and explain how the current in the circuit changes as the room temperature increases.

[2 marks]

Series Circuits

You can connect circuits in two ways — in series or in parallel (see next page).
You need to make sure that you understand the differences between the two types of circuit.

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.)

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.

Remember p.d. is potential difference or voltage.

- The current is the same everywhere in the circuit — $I_1 = I_2$ 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. Different components can have different voltages across them — the p.d. of 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 — $R_{total} = R_1 + R_2 + ...$

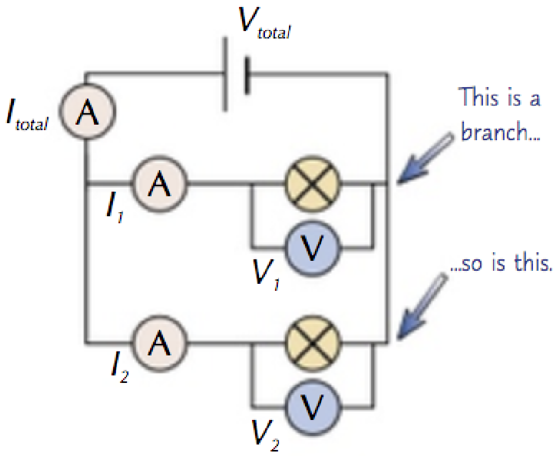
REVISION TIP

Series circuits — same current everywhere...

...and that'll help you remember how current works in a series circuit. Unlike current, the different components in a series circuit have different voltages across them. But the voltages of all the individual components will always add up to the total voltage of the power supply. Handy.

Parallel Circuits

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 are 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 one 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. $V_{total} = V_1 = V_2$ 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 splits or rejoins. The total current going into a junction equals the total current leaving it — charge can't 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.

REVISION TIP

Parallel circuits — part the current...

...and that'll help you remember how current works in a parallel circuit. The current leaving the power supply splits between the branches, so each branch has a different current through it. But the voltage in each branch is the same — and is the same as the total voltage of the power supply.

Charge, Voltage and Energy Change

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

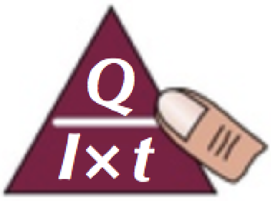
Charge Through a Circuit Depends on **Current** and **Time**

1) Current is the rate of flow of electrical charge (in amperes, A) around a circuit (see page 29).

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?

Answer: $Q = I \times t = 2.5 \times (4 \times 60 \times 60) = 36\,000$ C (36 kC)

The time needs to be in seconds.

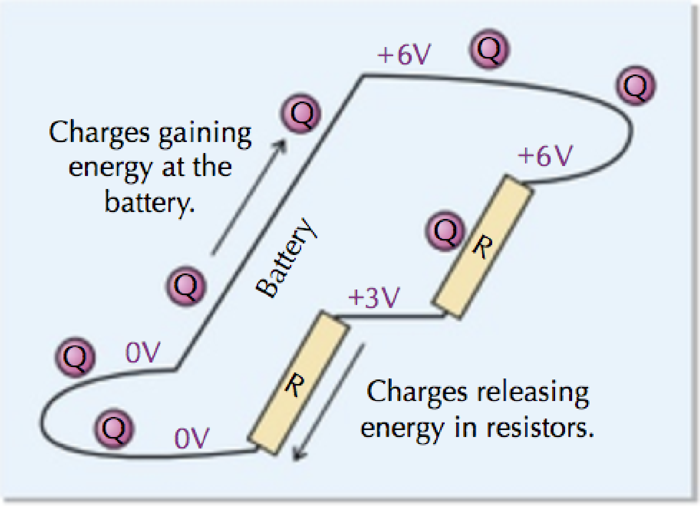
Charge is measured in coulombs, C.

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.



Charge, Voltage and Energy Change

You Can Calculate the Amount of Energy Transferred

1) The bigger the change in voltage, the more energy is transferred for a given amount of charge passing through the circuit.

2) 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.

3) This is because the charge is raised up 'higher' at the start — and as the diagram on the previous page shows, more energy will be dissipated in the circuit too.

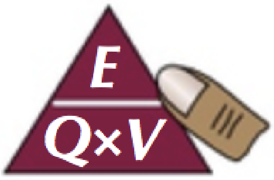
Voltage is the energy transferred per unit of charge passed

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

One volt is one joule per coulomb

5) 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

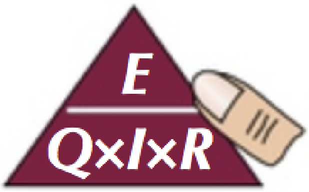


Example: 1.5 kC of charge passes through a kettle when it boils water using a 230 V supply. Calculate the amount of energy transferred as the kettle boils.

Answer: $E = Q \times V$
$= 1500 \times 230 = 345\,000$ J (345 kJ)

6) Combining this with $V = I \times R$ from page 31, 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



MATHS TIP

Make sure you always show your working...

...especially when you're substituting numbers into formulas, like the ones above. Writing out each step means that you're less likely to make mistakes when rearranging and substituting — and you'll usually still get some of the marks if you end up getting the final answer wrong.

Warm-Up & Exam Questions

Time to see what you can remember about parallel and series circuits, and energy change in circuits...

Warm-Up Questions

1) A series circuit contains a power supply, a lamp and a motor. The voltage across the lamp is 1.5 V. The voltage across the motor is 3.0 V. What is the voltage of the power supply?
2) True or false? The bigger the change in voltage, the more energy is transferred for a given charge.

Exam Questions

1 Two light bulbs are wired in series with a 12 V battery.

(a) Give **one** advantage of wiring the lights in parallel instead.

[1 mark]

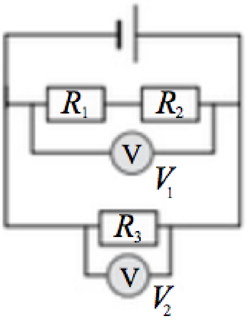
(b) The current through one of the bulbs is 0.5 A.
Calculate the total resistance of the series circuit. Give your answer in ohms.

[3 marks]

(c) Describe how the current in the circuit would change if there were three bulbs in series connected to the same battery.

[1 mark]

2 The diagram on the right shows a parallel circuit.



(a) The battery supplies a voltage of 4.20 V.
Give the voltages V_1 and V_2.

[1 mark]

(b) Each resistor has a resistance of 2.00 Ω.
Calculate the current through R_2. Give your answer in amps.

[4 marks]

3 A 3 V battery can supply a current of 5 A for 20 minutes before it needs recharging.

(a) State what carries the charge in an electric current through a metal conductor.

[1 mark]

(b) (i) State the equation that links charge, current and time.

[1 mark]

(ii) Calculate how much charge will pass through the circuit before the battery needs recharging.

[3 marks]

(c) State how much energy is transferred by the battery per coulomb of charge passed through the circuit. Explain your answer.

[2 marks]

(d) A different battery is used to supply electricity to a circuit.
It transfers a charge of 12 C over 3.0 seconds.
Calculate the total resistance of the circuit in ohms if 36 J of energy is transferred in 3.0 s.

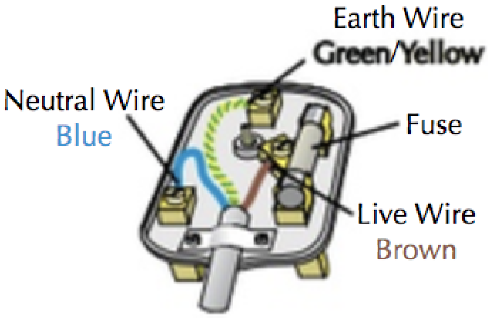
[4 marks]

Electrical Safety

Electricity can be dangerous, yet we use it every day — so it's important that we use it safely.

Appliances must be Earthed or Insulated

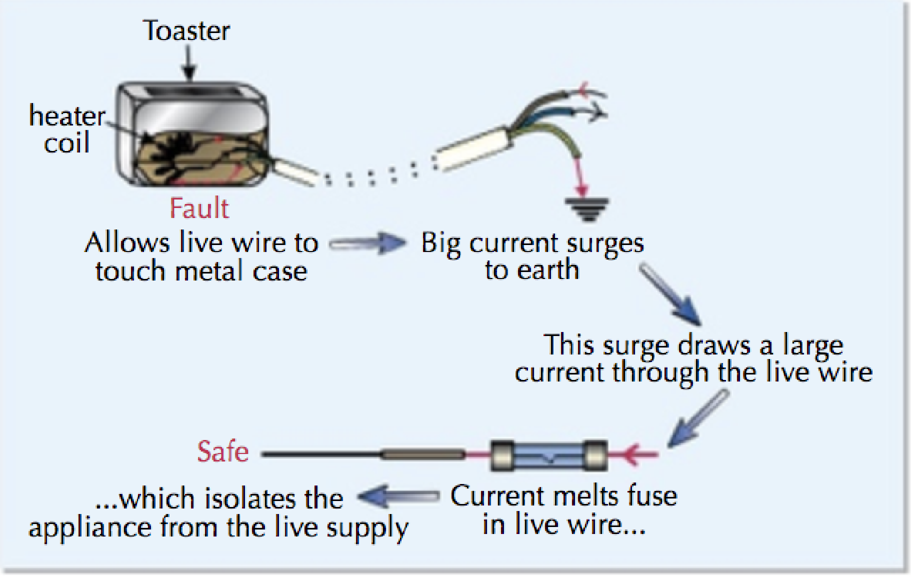
1) There are three wires in a plug — live, neutral and earth.
2) Only the live and neutral wires are usually needed, but if something goes wrong, the earth wire stops you getting hurt.
3) The live wire alternates between a high positive and negative voltage of about 230 V.
4) The neutral wire is always 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.



- 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 wire somehow touches the metal case, then because the case is earthed, a big current flows through the live wire, through the case and the earth wire.
2) This surge in current 'blows' (melts) the fuse (or trips the circuit breaker — see next page), 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.



Electrical Safety and Resistors

Fuses are great, but circuit breakers are better. If you don't believe me, read on and decide for yourself. I think resistors aren't half bad either (but whether you agree or not, you have to learn about them).

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 it's 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):

- 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.
- 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.
- 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.

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 useful 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.

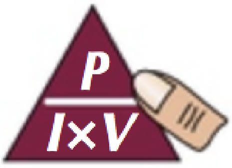
Energy and Power in Circuits

Most electrical appliances come with a power rating and a voltage rating.
You can use these to work out which fuse is most appropriate for the device.

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.

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

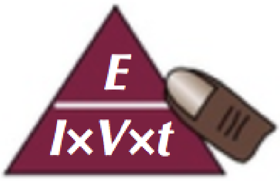
Example: A hair dryer is rated at 230 V and 1 kW. Find the fuse that it needs.

Answer: 1 kW = 1000 W
$I = P \div V = 1000 \div 230 = 4.34...$ 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.

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) Join that with the formula for electrical power above, and you get this formula for energy transferred:

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.

Answer: Use $E = I \times V \times t = 0.8 \times 3 \times (3 \times 60) = 432$ J

Time needs to be in seconds.

Choose the right fuse for the job

You need to make sure a fuse is rated as close as possible to the normal operating current of the appliance. If it's too low, the fuse will keep blowing all the time. If it's too high, the fuse won't blow when it needs to.

Warm-Up & Exam Questions

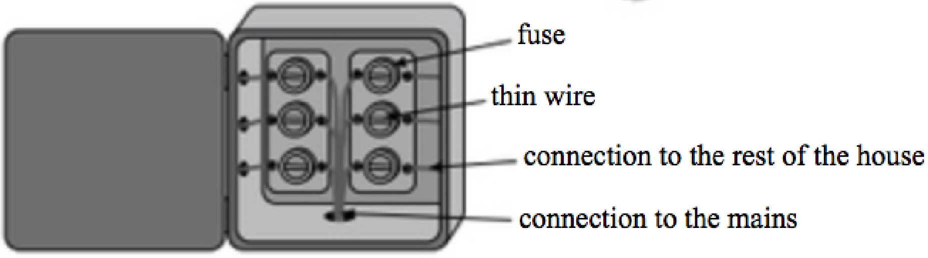
Now for some more questions — this time they're about safety, energy and power in circuits.

Warm-Up Questions

1) Name the three wires in a standard three-pin plug.
2) What happens to a resistor when an electric current passes through it?
   How is this useful in toasters?

Exam Questions

1 The picture below shows an old-fashioned household fuse box.



(a) Explain why houses have fuse boxes.

[1 mark]

(b) In old-fashioned fuse boxes like this, home-owners sometimes replaced old fuses with pennies. Explain why replacing fuses with pennies like this was dangerous.

[1 mark]

2 The heating element in a kettle usually contains a coil of wire made of Nichrome. When the kettle is turned on, current flows through the coil of wire.

(a) Explain why the coil of wire in the heating element is designed to have a high resistance.

[2 marks]

(b) The table below shows the power and voltage ratings for two kettles.

	Power (kW)	Voltage (V)
Kettle A	2.8	230
Kettle B	3.0	230

(i) State the equation linking electrical power, voltage and current.

[1 mark]

(ii) Calculate the current drawn from the mains supply by kettle A.
Give your answer in amps.

[3 marks]

(iii) A student is deciding whether to buy kettle A or kettle B.
She wants to buy the kettle that boils water faster. Both kettles are 90% efficient.
Suggest which kettle she should choose. Give a reason for your answer.

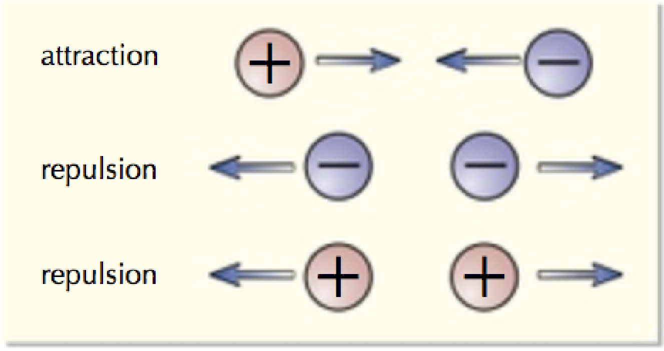
[2 marks]

Static Electricity

Static electricity is all about charges which are not free to move. Read on for more...

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.



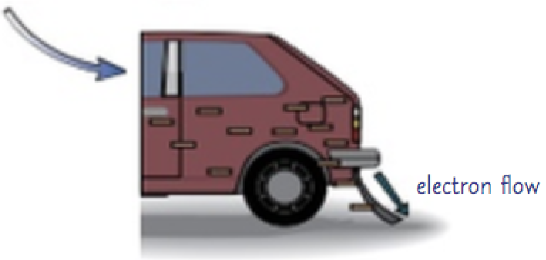
Conductors Conduct Charge — Insulators Don't

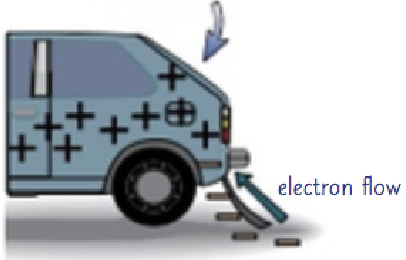
1) Materials that are electrical conductors conduct charge easily — a current can flow through them. They're usually metals, e.g. copper and silver.

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. 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 positive and negative 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.





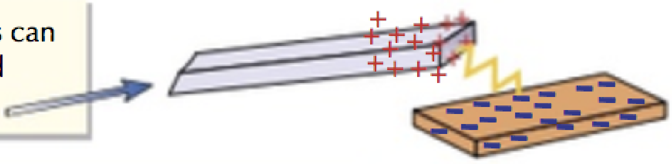
Investigating Static Electricity

When lots of static charge builds up, it often ends with a spark or a shock when it does finally move.

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.



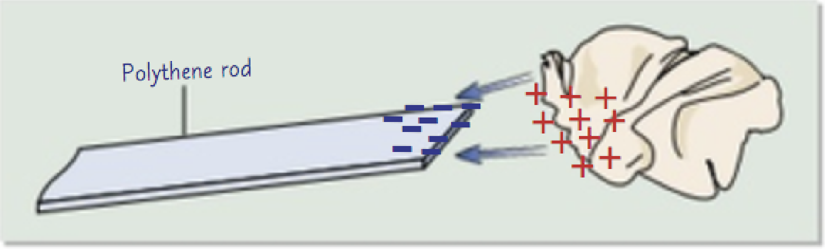
3) They can also jump to any earthed conductor that is nearby — which is why you can get static shocks from clothes, or getting out of a car.

4) This usually happens when the gap is fairly small. (But not always — lightning is just a really big spark, see page 48.)

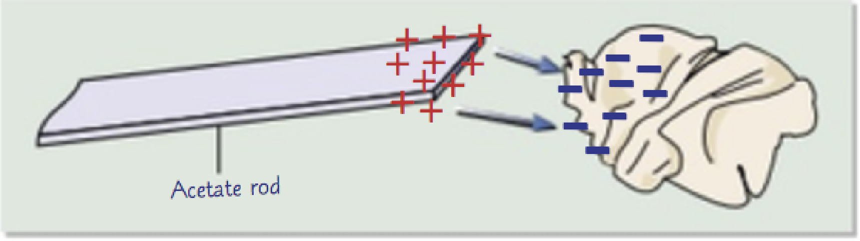
Experiments Can **Show** the **Effects** of **Static Electricity**

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 below. 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 on the next page.

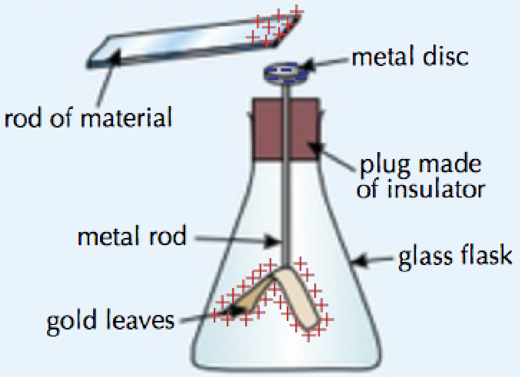
Investigating Static Electricity

How to **Check** if a Material is **Charged:**

1) Gold-Leaf Electroscope

PRACTICAL

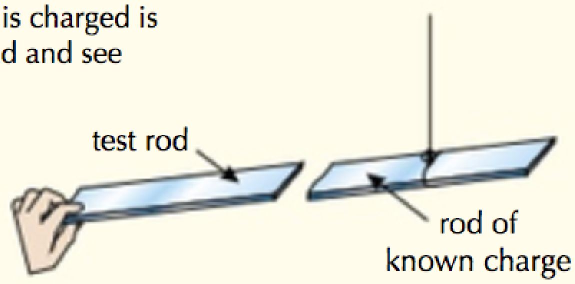
1) You can see whether a material is charged by using a gold-leaf electroscope.
2) A gold-leaf electroscope has a metal disc connected to a metal rod, at the bottom of which are attached two thin pieces of gold leaf.
3) When a rod with a charge is brought near to the disc of the electroscope, electrons 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

PRACTICAL

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

1) A Van de Graaff generator is used to demonstrate electrostatic charges.
2) It's made up of a rubber belt moving round plastic rollers underneath a metal dome.
3) An electrostatic charge is built up on the metal dome as the belt goes round.
4) 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.
5) The human body conducts charge, and like charges repel, so the charges will spread out as much as possible throughout your body.
6) The charge is strong enough to make your hairs repel each other and stand on end.

PRACTICAL TIP

Always take a moment to think about safety...

When you do any experiment, you should always assess the risks and try to reduce them as much as possible. Be careful not to shock yourself or others when working with static electricity.

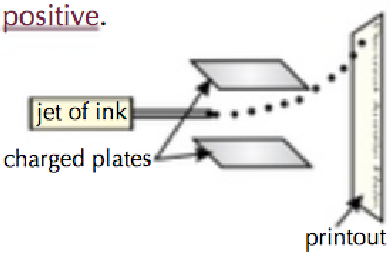
Static Electricity — More Examples

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

Static Electricity Being **Helpful**:

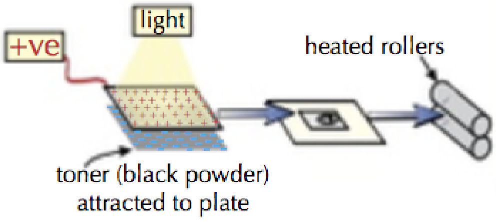
1) Inkjet Printer

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.



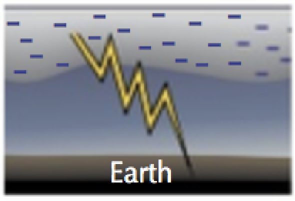
Static Electricity Being a **Nuisance**: Clothing Crackles

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

Static Electricity Being a **Serious Problem**:

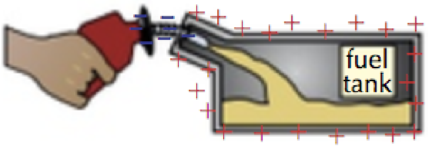
1) Lightning

Raindrops 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.



Warm-Up & Exam Questions

You might not be ecstatic about static electricity, but luckily you're nearly at the end of this section. There's only a few questions between you and a well deserved break...

Warm-Up Questions

1) What is an electrical conductor? Give an example.
2) What is an electrical insulator? Give an example.

Exam Questions

PAPER 2 **PRACTICAL**

1 A student rubs a polythene rod with a dusting cloth. The rod becomes negatively charged and the dusting cloth becomes positively charged. Grade 6-7

(a) Describe what happens to the electrons as the polythene rod is rubbed.

[2 marks]

(b) The polythene rod is now suspended from a string tied around its centre. The student has another charged object, with an unknown charge on it. Explain how the student can use the negatively charged polythene rod to determine the type of charge (positive or negative) on the object.

[3 marks]

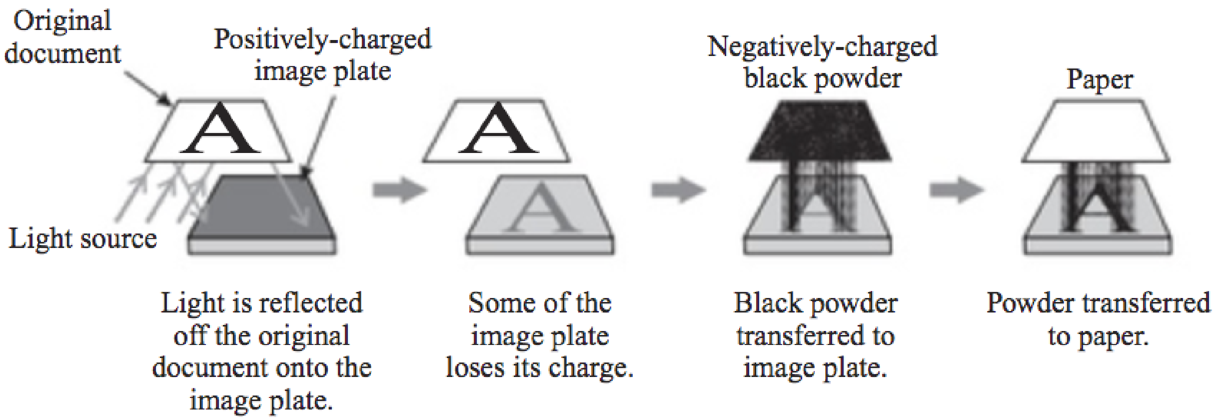
PAPER 2

2 A student prints a document from a computer using an inkjet printer. Grade 7-9

(a) An inkjet printer works by firing charged droplets of ink towards a piece of paper. Explain how the printer can control and alter the direction of the droplets of ink.

[3 marks]

(b) The student then photocopies the document. The diagram below shows the main steps that a photocopier uses to make a paper copy of a document.



(i) Before the process starts, the image plate is positively charged. Describe what causes some parts of the image plate to lose their charge.

[1 mark]

(ii) Describe how the original image is transferred to the paper after the light source has been reflected off it.

[5 marks]

Revision Questions for Section 2

That's it for Section 2 — time to power through these questions while you still have the energy.

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

Circuit Properties and Components (p.29-33) ☐

1) Explain what current, voltage and resistance are in an electric circuit. ☐
2) In a standard test circuit, describe where the ammeter and the voltmeter should be placed. ☐
3) What is the difference between a.c. and d.c.? ☐
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) Describe how the resistance of an LDR varies with light intensity. Give an application of an LDR. ☐

Series and Parallel Circuits (p.36-37) ☐

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

Charge, Voltage and Energy Change (p.38-39)

9) *If 80 C of charge is carried past a certain point in a wire in 2 s, how much current is flowing? ☐
10) Give the definition of a volt. ☐

Electrical Safety and Energy in Circuits (p.41-43) ☐

11) Sketch a properly wired three-pin plug. ☐
12) Explain how a fuse and earth wire work together in a plug. ☐
13) Explain how a Residual Current Circuit Breaker (RCCB) works. ☐
14) Give two advantages of using an RCCB instead of a fuse and an earth wire. ☐
15) Why does the wire in a fuse melt when the current gets too high? ☐
16) *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 ☐

Static Electricity (p.45-48) ☐

17) What causes the build-up of static electricity? Which particles move when static builds up? ☐
18) Describe how an acetate rod becomes electrically charged when it is rubbed with a duster. ☐
19) Give two examples of how static electricity can be dangerous. ☐

*Answers on page 207.

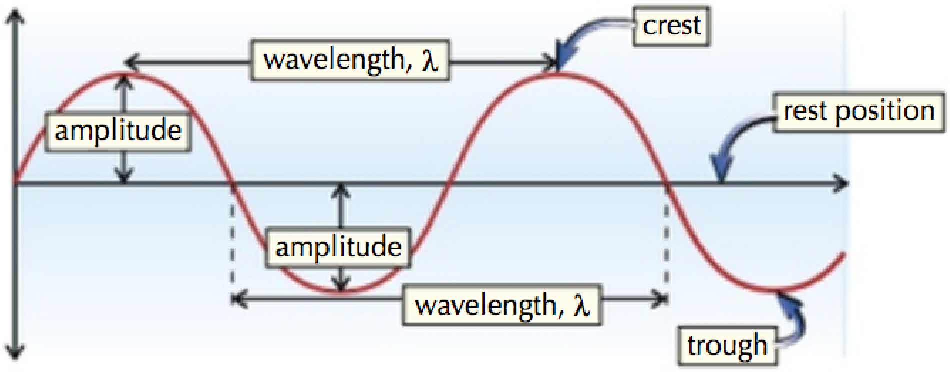
Waves — The Basics

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

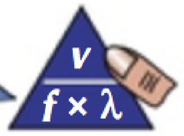
1) You need to learn this equation — and practise using it.

Speed = Frequency × Wavelength
(m/s) (Hz) (m)

OR

$$v = f \times \lambda$$

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



Example: Find the frequency of a light wave with wavelength 1×10^{-7} m. (Speed of light = 3×10^{8} m/s.)

Answer: 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.

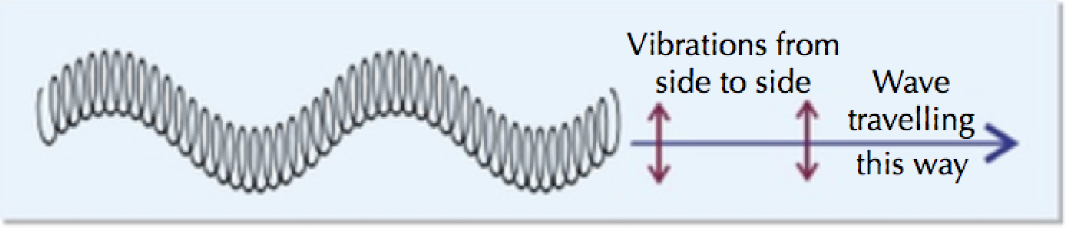
Waves — The Basics

Waves Can Be **Transverse...**

Most waves are transverse:

1) Light and all other EM waves (see p.55).
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.

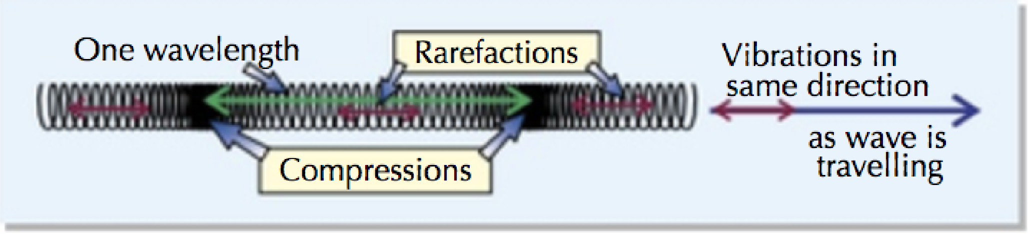


...or **Longitudinal**

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.



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 pages 55-56.

Waves only transfer energy and information — not matter...

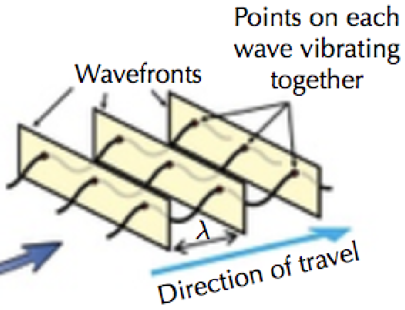
It's really important that you understand this stuff, or the rest of this section is likely to be a bit of a blur. Make sure you understand the diagrams of the two types of wave above and can distinguish between them.

Wave Behaviour

If you've ever wondered why the sound of a fast car speeding past you changes as it comes towards you and then as it moves away from you, I reckon you're going to enjoy this page.

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.



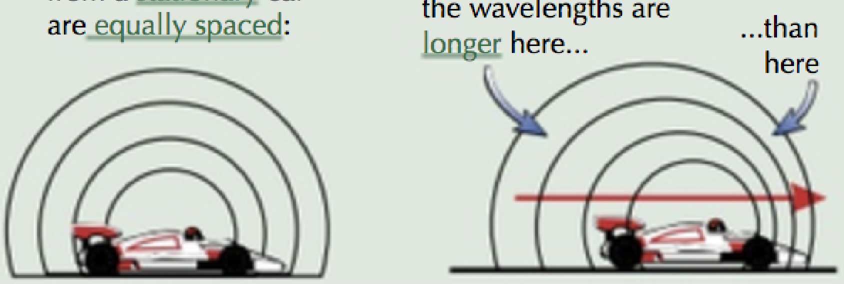
The **Motion** of a **Source** Affects **Frequency** and **Wavelength**

1) If a wave source is moving towards an observer, the frequency of the wave they observe will be higher and the wavelength will be shorter than the original wave emitted by the source.
2) If a wave source is moving away from an observer, the frequency of the wave they observe will be lower and the wavelength will be longer than the original wave emitted by the source.
3) This is because the wave's speed is constant — 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.

Example: the sound of a racing car engine changes as it drives past you.

1) The sound waves from a stationary car are equally spaced:

2) But for a moving car, the wavelengths are longer here... ...than here



3) So the frequency of the sound waves is higher when the car is moving towards you, and lower when the car is moving away from you.

4) This is called the Doppler effect.

Moving the source of a wave will affect what you observe

The Doppler effect is tricky to get your head round, so don't panic if it takes a while to sink in. You'll have heard it in everyday life with sound waves, e.g. how the sound of an ambulance siren changes as it passes you. But remember, it applies to all waves — there's a bit about how it works in light waves on page 150.

Warm-Up & Exam Questions

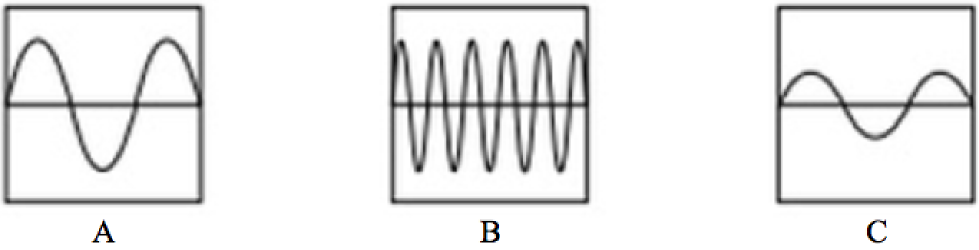
Now to check what information's actually been transferred to your brain over the last three pages...

Warm-Up Questions

1) Define the following: a) wavelength b) period (of a wave).
2) Find the wavelength of a wave with a frequency of 6×10^6 Hz that is travelling at 3×10^8 m/s.
3) Describe how transverse and longitudinal waves are different in terms of the direction of their vibrations.
4) True or false? Waves transfer energy, information and matter.
5) Explain what is meant by a wavefront.

Exam Questions

1 The diagram shows the graphs of three waves A, B and C. Each graph has the same scale.



(a) What is meant by the amplitude of a wave?

[1 mark]

(b) Which of the following is correct?

☐ **A** A and B have the same wavelength.

☐ **B** B and C have the same wavelength.

☐ **C** A and C have the same wavelength.

☐ **D** None of the waves have the same wavelength.

[1 mark]

2 The Doppler effect can be used to learn information about distant stars.

(a) State what is meant by the Doppler effect.

[2 marks]

(b) Explain why the Doppler effect occurs.

[3 marks]

(c) An astronomer measures the frequencies of the electromagnetic waves emitted by a distant star. She finds that they are slightly lower than those of a similar star that is known not to be moving either towards or away from the Earth.

Suggest whether this indicates that the distant star is moving towards or away from the Earth. Explain your reasoning.

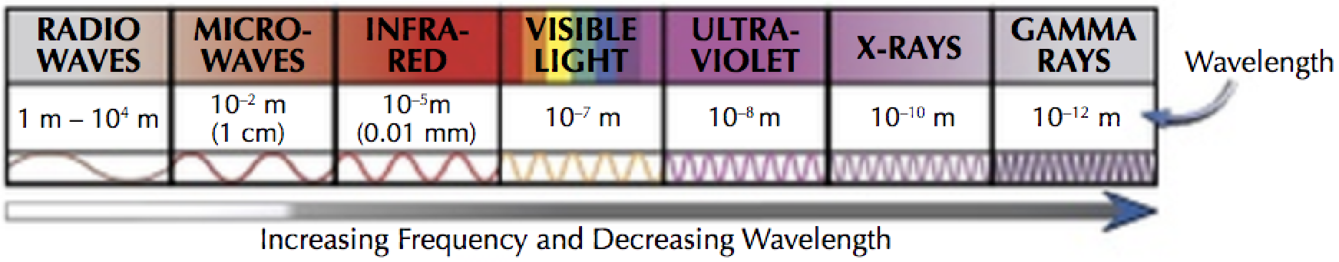
[2 marks]

Uses of Electromagnetic Waves

EM waves are great — there's so much you can do with them. Here's a good look at the uses of EM waves.

There are **Seven Types** of **Electromagnetic (EM) Waves**

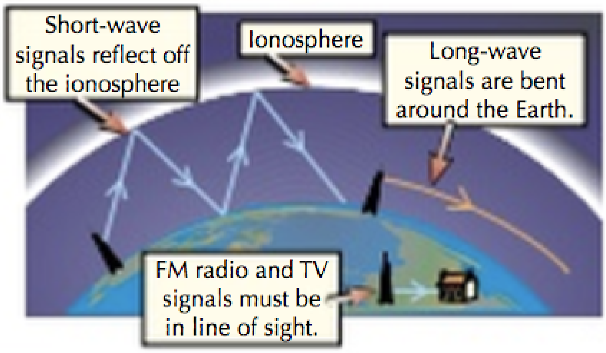
1) Electromagnetic (EM) waves with different wavelengths have different properties. They're grouped into seven types by their wavelength (but the types actually merge to form a continuous spectrum).



RADIO WAVES	MICRO-WAVES	INFRA-RED	VISIBLE LIGHT	ULTRA-VIOLET	X-RAYS	GAMMA RAYS
1 m – 10^4 m	10^{-2} m (1 cm)	10^{-5} m (0.01 mm)	10^{-7} m	10^{-8} m	10^{-10} m	10^{-12} m

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).

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 **Cooking**

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 82-83) of the food.

You need to remember the seven types of EM waves...

...and you need to remember them in order. A mnemonic can make this easier. My favourite is: Raging Martians Invaded Venus Using X-ray Guns. But you can make up your own if you prefer.

Uses of Electromagnetic Waves

Infrared radiation and visible light are both ridiculously useful EM waves that we use all the time.

Infrared Radiation is Used for **Heating** and to **Monitor Temperature**

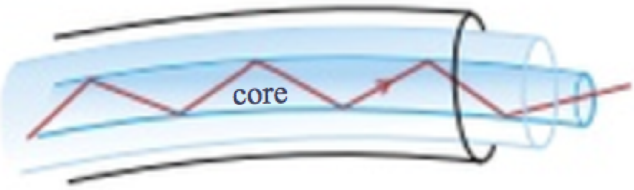
1) Infrared radiation (or IR) is also known as heat radiation. Electrical heaters radiate IR to keep us warm, and things like grills use IR to cook food.

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.

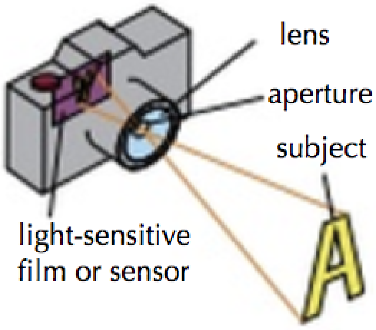


This is known as total internal reflection — see p.65.

Visible Light is Also Useful for **Photography**

It sounds pretty obvious, but photography would be 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.



Optical fibres are amazingly useful...

Optical fibres are used to send information over long distances. The EM waves travel fast. And the signal is less prone to interference than in a copper wire, so there's more chance of it reaching the other end clearly.

Uses of Electromagnetic Waves

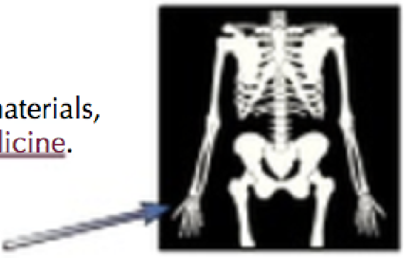
That's right — yet another page on the uses of EM waves. Ultraviolet, X-rays and gamma rays are the shortest waves in the spectrum, and we use them for all sorts of fancy stuff...

Ultraviolet is Used in Fluorescent Lamps

The Sun also emits a lot of UV radiation — it can cause damage to skin cells (see p.58).

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 76) than filament light bulbs.

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 that lead to cancer. 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, cook it or preserve it some other way.
3) The food is not radioactive afterwards, so it's perfectly safe to eat.

Each type of EM wave has multiple uses

You're probably getting the idea by now that we use electromagnetic radiation an awful lot. There are even more uses than the examples on these pages, but these are the ones you need to make sure you know.

Dangers of Electromagnetic Waves

Okay, so you know how useful electromagnetic radiation can be — well, it can also be pretty dangerous.

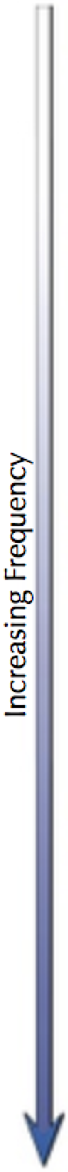
Some **EM Radiation** Can be **Harmful** to People

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

1) 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.
2) Microwave ovens need to have shielding to prevent microwaves from reaching the user.

Infrared

1) 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.
2) You can protect yourself using insulating materials to reduce the amount of IR reaching your skin.

Ultraviolet

1) 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.
2) 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

1) 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.
2) 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.

Warm-Up & Exam Questions

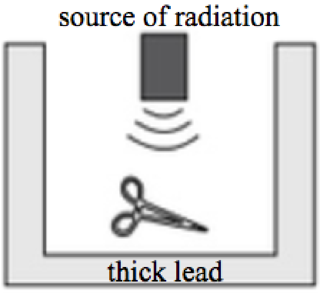
There are quite a few different sorts of electromagnetic waves — and you never know which ones might come up in the exams... So use these questions to check which ones you're still a bit hazy on.

Warm-Up Questions

1) Of the seven types that electromagnetic waves are usually grouped into, which has the longest wavelength?
2) True or false? Radio waves travel more slowly than visible light through free space.
3) What type of EM radiation is used in grills and electric heaters?
4) Explain how gamma rays can be dangerous for the human body and describe one way of reducing the risk when using them.

Exam Questions

1 The diagram shows electromagnetic radiation being used to sterilise a surgical instrument.



(a) State what type of electromagnetic radiation is being used.

[1 mark]

(b) A similar process can be used to treat fruit before it is exported to other countries. Suggest why this process is used.

[2 marks]

2 Optical fibres have many practical uses.

(a) Which type of electromagnetic wave is typically transmitted in optical fibres?

☐ **A** radio waves ☐ **B** visible light

☐ **C** microwaves ☐ **D** X-rays

[1 mark]

(b) Explain how data is transmitted through optical fibres.

[2 marks]

(c) Give **one** application of optical fibres.

[1 marks]

3 Mobile phones use microwaves to transmit signals.

(a) Suggest why people might be worried that excessive mobile phone use could be harmful.

[1 mark]

(b) Explain why it would be more dangerous to use infrared radiation instead of microwaves for mobile phone signals.

[2 marks]

Exam Questions

4 The radio transmitter shown transmits long-wave and short-wave radio signals. The house receiving the signal is a long way from the transmitter.

(a) Describe how the long-wave and short-wave radio signals from the transmitter are each able to reach the house.

[2 marks]

(b) The owner of the house decides to get satellite TV installed.

(i) State what type of electromagnetic radiation is used to send signals to satellites.

[1 mark]

(ii) Describe how satellite TV signals are transmitted from a transmitter on the ground to the house.

[2 marks]

5 A naturalist uses a night-vision camera to capture an image of a fox, as shown below.

Explain how the night-vision camera allowed this image to be taken.

[2 marks]

6 X-rays are used by truck scanners at country border control points.

(a) X-rays are passed through a truck. Explain how an image of the objects in the truck is formed.

[4 marks]

(b) During a scan, the driver and any passengers are asked to step outside the vehicle for their own safety. Suggest why this happens.

[2 marks]

7 Ultraviolet radiation can damage skin cells and cause cancer in humans.

(a) Fluorescent lamps make use of ultraviolet radiation. State whether or not fluorescent lamps are harmful to humans. Explain your answer.

[2 marks]

(b) Photographers sometimes use ultraviolet filters to prevent ultraviolet radiation from reaching the camera's sensor or film. Describe how a camera creates a photograph using visible light, and how the photographer can control the amount of visible light entering it.

[3 marks]

Reflection of Waves

All waves can be reflected. Reflection happens when light bounces off a surface.

Reflection of Light Lets Us See Things

1) Visible light is a transverse wave (see page 52), 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) The law of reflection applies to every reflected ray:

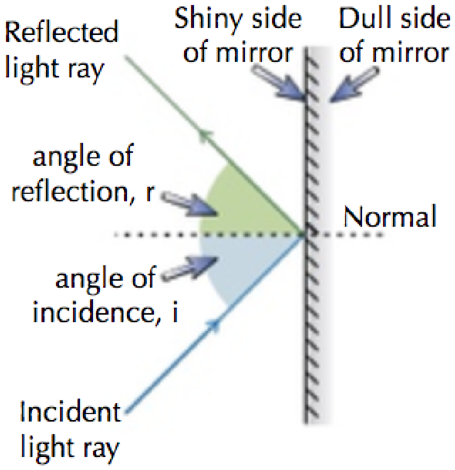
Angle of incidence = Angle of reflection

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.

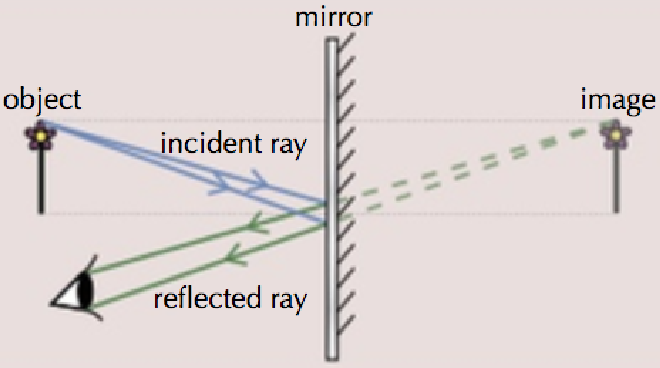
7) The angle of incidence is the angle between the incoming wave and the normal. The angle of reflection is the angle between the reflected wave and the normal.

You can draw ray diagrams, like the ones below, to show the path that light waves travel along.

Rays are always drawn as straight lines.



- You'll probably have gathered from years of looking in mirrors that they form images of whatever's in front of them.
- 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.



The law of reflection applies to all reflected rays...

...if you know the angle of incidence then you know the angle of reflection — it's as simple as that.

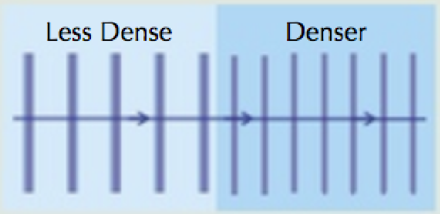
Refraction of Waves

Refraction occurs when a wave slows down or speeds up at a boundary between two materials.

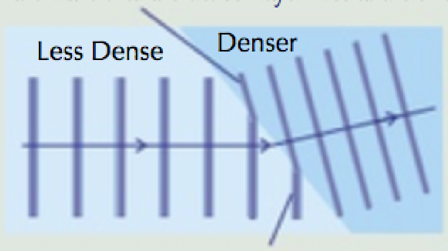
Waves Can be **Refracted**

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.

Draw a **Ray Diagram** for a **Refracted Wave**

There are more ray diagrams on pages 63 and 64.

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).

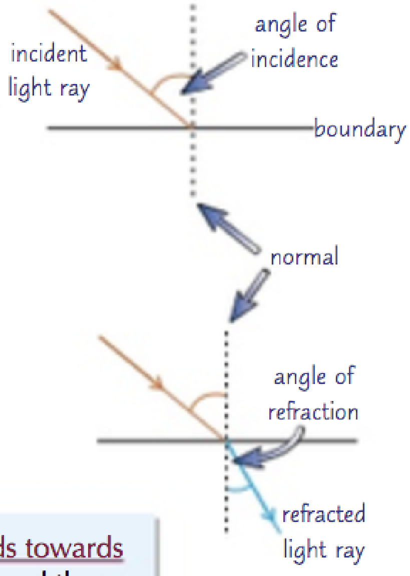
2) Draw an incident ray that meets the normal at the boundary.

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.

5) 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.

6) If the second material is less dense, the angle of refraction is larger than the angle of incidence.



Hitting a boundary at an angle can lead to refraction

If you're asked to draw a ray diagram in an exam, make sure it's clear and a sensible size. You should always use a ruler, a protractor and a nice sharp pencil to draw ray diagrams too.

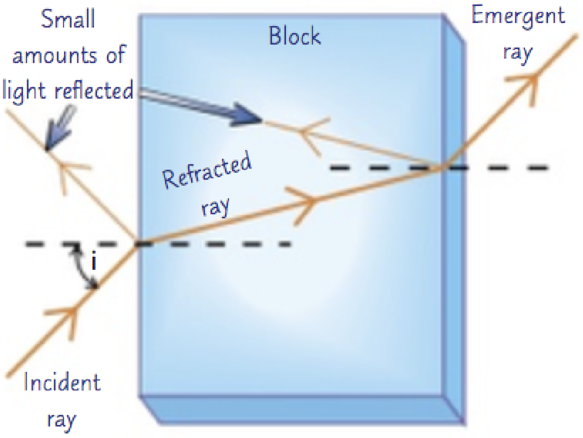
Refraction of Waves

PRACTICAL

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

Rays Passing Through a **Glass Block** are Refracted **Twice**

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 on to the 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.)

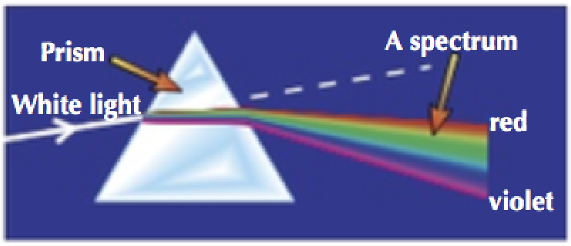


6) The light ray that emerges on the other side of the block is now travelling in the same direction it was to begin with — it's been refracted towards the normal and then back again by the same amount.

Triangular Prisms **Disperse** White Light

1) You'll get an interesting effect if you shine white light into a triangular prism.

2) 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 the prism and the different wavelengths are refracted by different amounts.



Red is bent the least and violet is bent the most.

3) A similar effect happens as the light leaves the prism, which means you get a nice rainbow effect.

PRACTICAL TIP

Use appropriate equipment to get better results...

Try to use a thin, bright beam of light because it will be much easier to trace. Not only will you be able to see the light more clearly, but your measurements will be more accurate too.

Refractive Index and Snell's Law

Make sure you're happy with the last two pages before going on, because there's more refraction coming...

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:

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

$$n = \frac{c}{v}$$

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.).

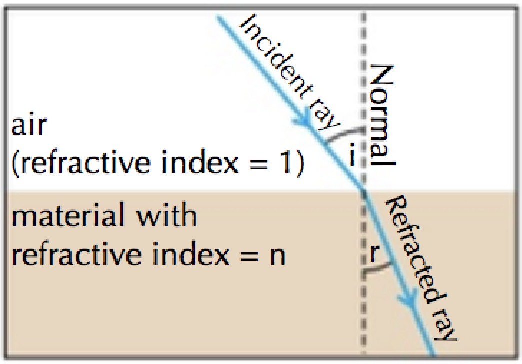
4) According to Snell's law, the angle of incidence, angle of refraction and refractive index are all linked...

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.

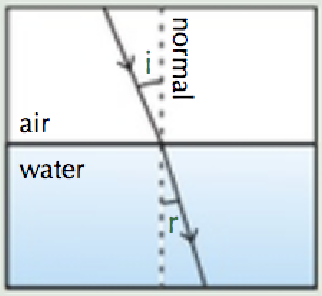
Example: A beam of light travels from air into water. The angle of incidence is 23°. The refractive index of water is 1.33. Calculate the angle of refraction to the nearest degree.

Answer: Rearrange the equation: $\sin r = \frac{\sin i}{n}$

Then substitute the values in: $\sin r = \frac{\sin 23°}{1.33} = 0.29....$

Use the inverse function of sine to find r:

$r = \sin^{-1}(0.29...) = 17.08.... = 17°$



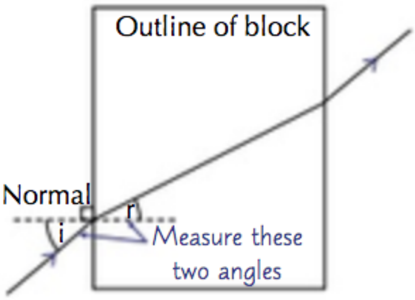
Refractive Index and Snell's Law PRACTICAL

Believe it or not, there are another couple of practicals that you can do with glass blocks coming right up.

Find the Refractive Index of Glass Using a Glass Block

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 page 63.

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.



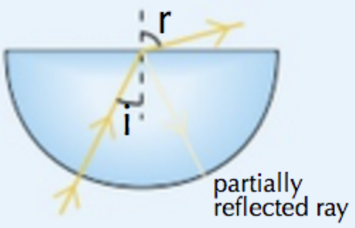
The refractive index of glass should be around 1.5, so if you get a ridiculous answer then you've gone wrong somewhere.

Use Semicircular Blocks to Show Total Internal Reflection

1) As you've seen, light going from a material with a higher refractive index to a material with a lower refractive index speeds up and 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.

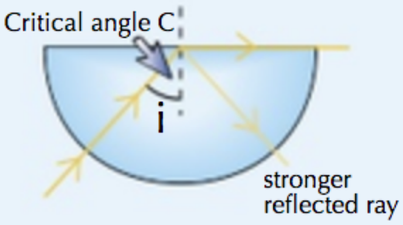
If the angle of incidence (*i*) is...

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



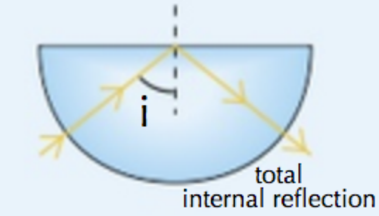
...less than the critical angle:

Most of the light passes out but a little bit of it is internally reflected.



...equal to the critical angle:

The emerging ray comes out along the surface. There's quite a bit of internal reflection.



...greater than the critical angle:

No light comes out. It's all internally reflected, i.e. total internal reflection.

Snell's Law and Critical Angles

You'll be pleased to know that this page covers the final bits and bobs you need to know about Snell's law.

You Can Use **Snell's Law** to find **Critical Angles**

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

This equation comes from Snell's law that you saw on page 64 — you don't need to know how, but you do need to learn both equations.

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

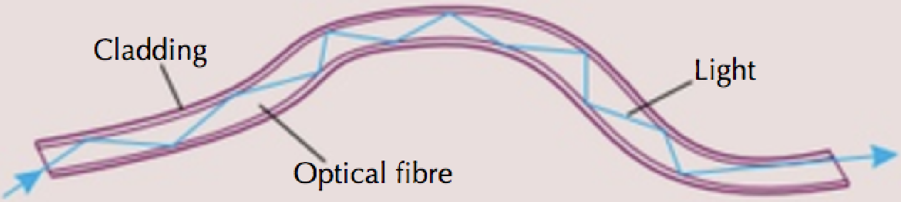
n is the refractive index of the material.

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

Optical Fibres and **Prisms** Use **Total Internal Reflection**

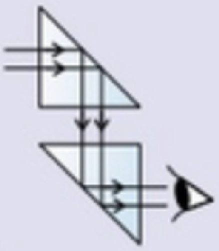
Optical Fibres

1) Optical fibres (see page 56) that are made of plastic or glass 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.
3) It only stops working if the fibre is bent too sharply.



Prisms

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.



The critical angle is always measured from the normal...

Remember that total internal reflection only works when light tries to pass into something less dense (i.e. with a lower refractive index), for example, when light passes from a glass block into the air.

Warm-Up & Exam Questions

There you go — a little reflection, a lot of refraction. Here are a few questions to check it all went in.

Warm-Up Questions

1) Is visible light a transverse or longitudinal wave?
2) A ray of light passes into a rectangular glass block, through it, and out again. How many times will the light ray have been refracted?
3) State Snell's law.
4) Describe an experiment you could do to find the refractive index of a glass block.

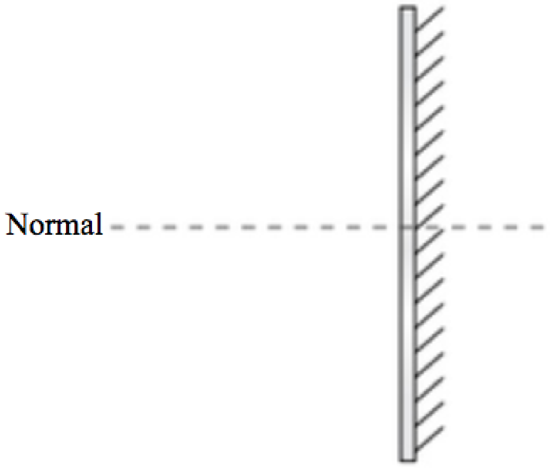
Exam Questions

1 A student shines a beam of light into a mirror. Grade 6-7

(a) State the law of reflection.

[1 mark]

(b) A ray of light with an angle of incidence of 35° is reflected from a mirror. Copy the diagram of the mirror and the normal shown below and sketch a ray diagram to show both the incident and reflected rays.



[2 marks]

(c) The student swaps the mirror for a glass block, and shines the beam of light into it at an angle to the normal. Explain why the beam of light changes direction when it travels from the air into the block and state the name of this effect.

[3 marks]

2 Endoscopes use optical fibres to look inside a patient's body. When light meets the boundary between the optical fibre core and the outer cladding, there is total internal reflection. Grade 6-7

(a) An optical fibre core has a refractive index of 1.54. Calculate the critical angle of the core material.

[3 marks]

Exam Questions

(b) Suggest why bending the endoscope too sharply may result in reduced image quality.

[2 marks]

3 A semicircular acrylic block is placed in water. Light passes through the block into the water. The critical angle (C) of the acrylic-water boundary for the light is 63.2°.

Grade 6-7

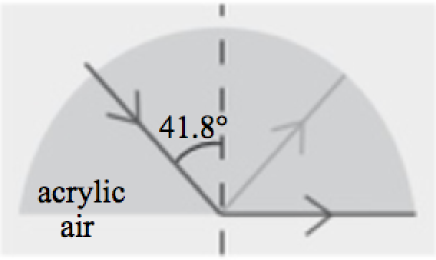
(a) State what is meant by the **critical angle** for a boundary.

[1 mark]

(b) A ray of light meets the acrylic-water boundary at an angle of incidence of 75°. Describe what will happen to the ray of light at the boundary.

[1 mark]

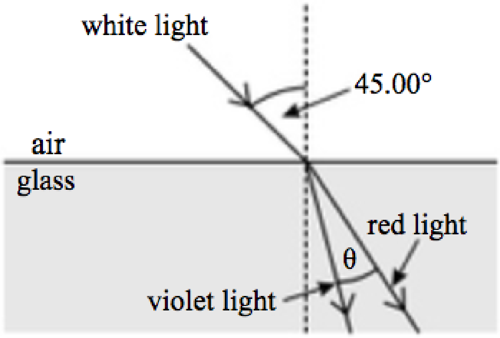
(c) The diagram shows a ray of light hitting the boundary between the same acrylic block and the air. Calculate the refractive index of the acrylic.



[3 marks]

4 The diagram shows white light refracting at an air-glass boundary and separating into colours.

Grade 7-9



(a) The refractive index of glass for red light is 1.514. Calculate the angle of refraction for red light.

[4 marks]

(b) Explain why the ray of white light would not separate into colours if it crossed the boundary along the normal.

[2 marks]

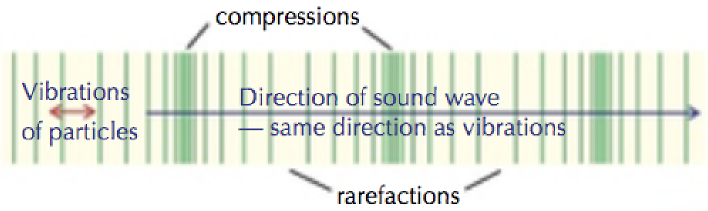
(c) The refractive index of glass for violet light is 1.528. Calculate the angle θ shown in the diagram.

[4 marks]

Sound Waves

You hear sounds when vibrations reach your eardrums. Read on to find out how sound waves work...

Sound Travels as a Wave



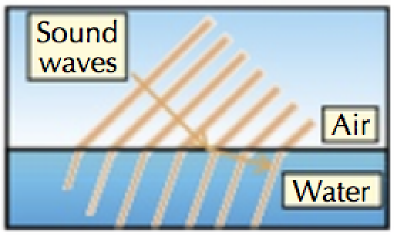
1) Sound waves are longitudinal waves caused by vibrating objects. The vibrations are passed through the surrounding medium as a series of compressions.

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.

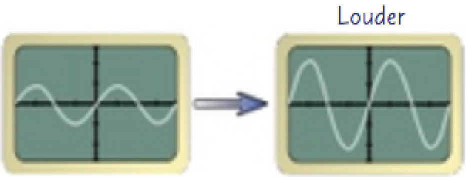


An Oscilloscope Can Display Sound Waves

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.



Sound Waves

All sounds have pitch. You can measure the pitch of sounds using an oscilloscope. Here's how...

The **Higher** the **Frequency**, the Higher the **Pitch**

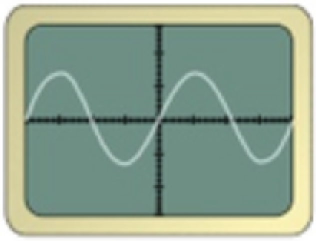
1) Frequency is the number of complete vibrations each second, and it's measured in hertz (Hz) — 1 Hz is equal to 1 vibration per second. Other common units are kHz (1000 Hz) and MHz (1 000 000 Hz).

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 below).

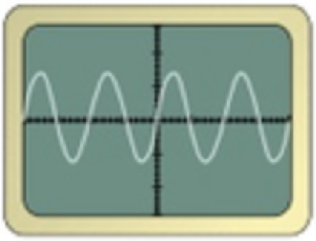
3) If the source of sound vibrates with a high frequency the sound is high-pitched, e.g. a squeaking mouse. If the source of sound vibrates with a low frequency the sound is low-pitched, e.g. a mooing cow.

4) The traces below are very important, so make sure you know them.

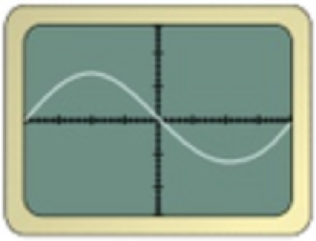
Original Sound



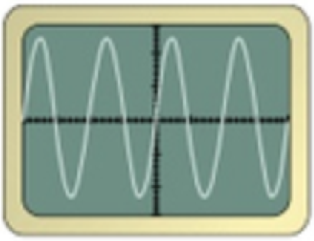
Higher pitched



Lower pitched



Higher pitched and louder

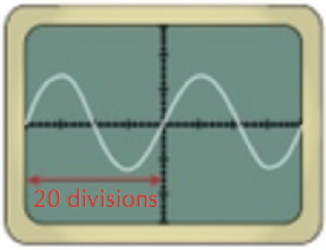


Use an **Oscilloscope** to Find the **Frequency** of a **Wave**

PRACTICAL

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.

Time divisions set to 0.0001 s



Here 1 cycle crosses 20 divisions, so
period = 20 × 0.00001 s = 0.0002 s.

Frequency = 1 ÷ period (see page 51)
= 1 ÷ 0.0002 s = 5000 Hz = 5 kHz.

Frequency is measured in hertz (Hz)

Remember: if the waves on the oscilloscope get closer together, the frequency has increased and the sound will be higher pitched. If they get taller, the amplitude has increased and the sound will be louder.

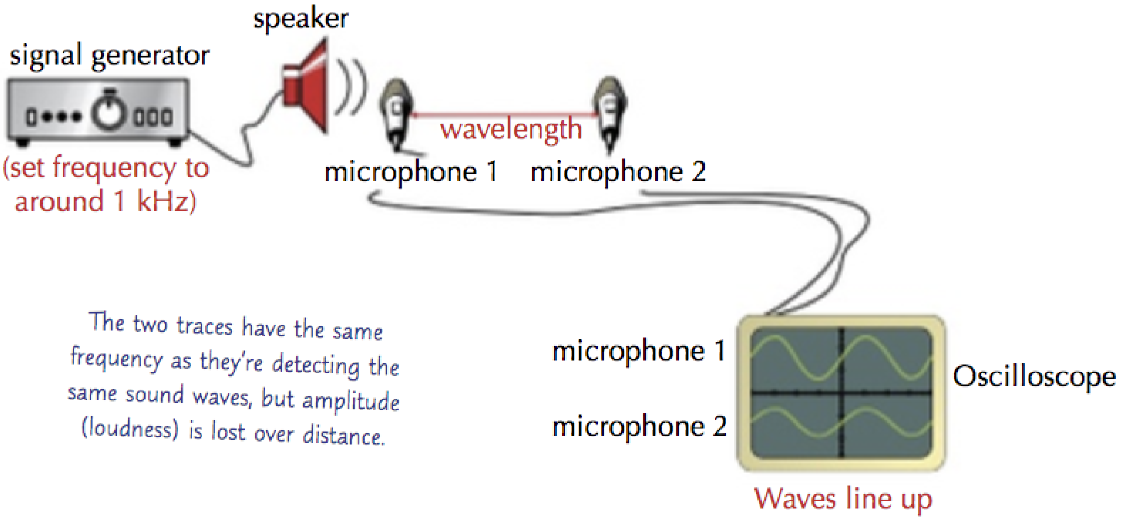
Sound Waves

PRACTICAL

This page is all about how to measure the speed of sound. Exciting stuff.

You Can Use an **Oscilloscope** to Measure the **Speed** of Sound

1) 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:



2) The detected waves at each microphone can be seen as a separate wave on the oscilloscope.

3) 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.

4) Measure the distance between the microphones to find the wavelength (λ).

5) You can then use the formula $v = f \times \lambda$ (see page 51) 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.

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

PRACTICAL TIP

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 else 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 "speed = distance ÷ time" (see page 1) to work out the speed of the sound waves.

Warm-Up & Exam Questions

Now for some more questions — work through them all to see if you've got your sound wave facts sorted.

Warm-Up Questions

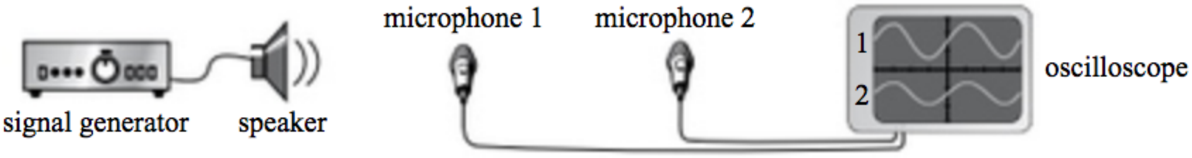
1) Is sound a transverse or longitudinal wave?
2) What is the frequency range for human hearing?
3) What is the relationship between the loudness of a sound and its amplitude?

Exam Question

PAPER 2 **PRACTICAL**

Grade 6-7

1 The diagram below shows how an oscilloscope can be used to display sound waves by connecting microphones to it. Trace 1 on the oscilloscope shows the sound waves detected by microphone 1 and trace 2 shows the sound waves detected by microphone 2.



(a) (i) A student used this equipment to find the speed of sound. The steps below show the method he used. Put the steps into the correct order by copying the table and numbering the boxes. The first one has been done for you.

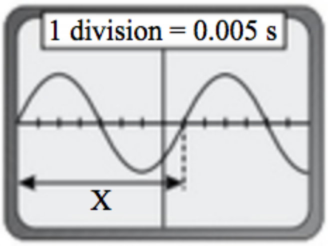
Statements	Order
Measure the distance between the microphones. This is the wavelength.	
Stop moving microphone 2 when the traces line up.	
Use the measured distance and the frequency of the signal generator to find the wave speed.	
Begin with both microphones at an equal distance from the speaker.	1
Keeping microphone 1 fixed, slowly move microphone 2 away from the speaker (keeping it in line with microphone 1), causing trace 2 to move.	

[3 marks]

(ii) With the signal generator set to 50 Hz, the distance between the microphones was measured to be 6.8 m. Calculate the speed of sound in air in m/s.

[2 marks]

(b) One microphone is removed and the signal generator is adjusted. The diagram shows the trace produced on the oscilloscope.



(i) Which quantity is represented by X on the trace?

☐ **A** wavelength ☐ **B** amplitude

☐ **C** frequency ☐ **D** time period

[1 mark]

(ii) Calculate the frequency of the wave in hertz.

[2 marks]

Revision Questions for Section 3

That wraps up Section 3 — time to put yourself to the test and find out how much you really know.

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

Wave Basics (p.51-53) ☑

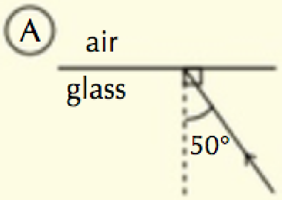
1) Draw a diagram to illustrate frequency, wavelength and amplitude. ☑
2) What is the formula used to calculate the frequency of a wave from the period? ☑
3) *Find the frequency in hertz of a wave with a wavelength of 0.3 m and a speed of 150 m/s. ☑
4) What is the main difference between a transverse wave and a longitudinal wave? ☑

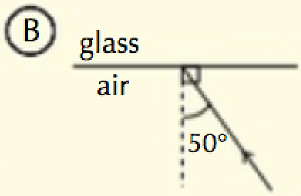
Electromagnetic Waves (p.55-58) ☑

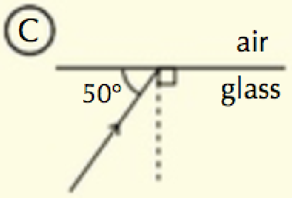
5) Write down all seven types of EM radiation in order of increasing frequency and decreasing wavelength. ☑
6) Write down all the colours of visible light in order of increasing frequency and decreasing wavelength. ☑
7) Describe one common use of each of the seven types of EM waves. ☑
8) Which is generally more hazardous — low frequency or high frequency EM radiation? ☑
9) Describe the harmful effects on the human body that can be caused by UV rays. ☑

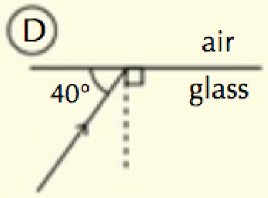
Reflection and Refraction (p.61-66) ☑

10) *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? ☑
11) 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°). ☑
12) *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? ☑
13) *For each of the diagrams A to D below, state whether the ray of light would be totally internally reflected or not. (The critical angle for glass is approximately 42°.) ☑





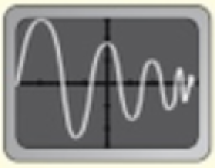




14) Give one practical use of total internal reflection. ☑

Sound Waves (p.69-71) ☑

15) True or false? Sound waves are reflected by hard surfaces. ☑
16) 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? ☑



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

*Answers on page 209.

Conservation of Energy

I hope you're feeling lively, because this module is all about energy. The main thing to remember about energy is that you can never make it or destroy it — you just transfer it from one energy 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 in a chemical reaction, e.g. food, fuel.
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 by electromagnetic waves (like light — see page 55), 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, or dissipated — but it can never be created or destroyed. The total energy of a closed system has no net change.

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

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.

EXAM TIP

No matter what store it's in, it's all energy...

In the exam, make sure you refer to energy in terms of the store it's in. For example, if you're describing energy in a hot object, say it 'has energy in its thermal energy store'.

Wasted Energy

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

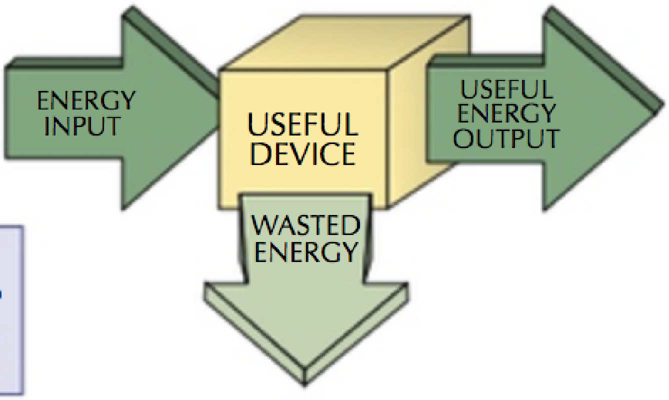
Most Energy Transfers Involve Some Losses, Often by Heating

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 84.

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 previous page), 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.

Before you know what's waste, you've got to know what's useful...

If you're trying to work out how a device is wasting energy, the first thing you should do is figure out which store is useful. For example, for a phone charger, only energy that's transferred to the chemical energy store of the phone's battery is useful. Then you know any energy that ends up anywhere else is wasted.

Energy Efficiency

Devices have energy transferred to them, but only transfer some of it to useful energy stores. Wouldn't it be great if we could tell how much the device usefully transfers? That's where efficiency comes in.

You can Calculate the Efficiency of an Energy Transfer

The efficiency of any device is defined as:

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

The total energy output will be the same as the total energy input, because of the principle of conservation of energy (see p.74).

You should give efficiency as a percentage, e.g. 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:

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.

Answer:
$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy output}} \times 100\%$$
$$= \frac{84\,000}{216\,000} \times 100 = 38.888... = 39\% \text{ (to 2 s.f.)}$$

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.

You can compare devices more easily if you calculate their efficiencies...

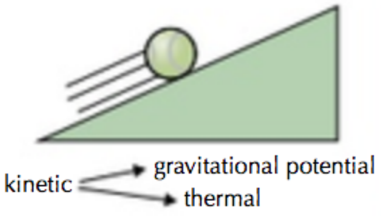
As long as you remember to multiply by 100 to get a percentage, the efficiency equation's not too bad to use. Where it can get tricky is working out what is useful energy — some devices may transfer energy to more than one useful store, so make sure that you've factored them all into your calculation.

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 — you need to understand the patterns, and analyse how energy moves between stores in different situations.

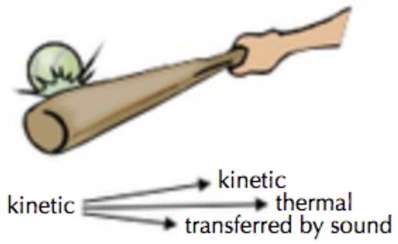


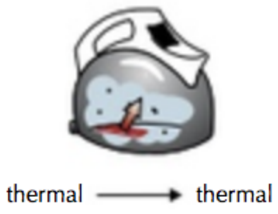
A BALL ROLLING UP A SLOPE:

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.



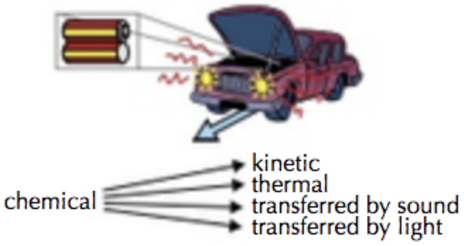


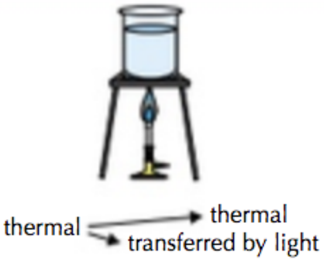
AN ELECTRIC KETTLE BOILING WATER:

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.

REVISION TIP

Energy is transferred between the different stores of objects...

Energy stores pop up everywhere in physics. You need to be able to describe how energy is transferred, and which stores it gets transferred between, for any scenario. So make sure you know all the energy stores and transfer methods like the back of your hand.

Sankey Diagrams

This is another bit of physics where you'll have to tackle some maths-based questions. Fantastic. So best prepare yourself — here's what Sankey diagrams are all about...

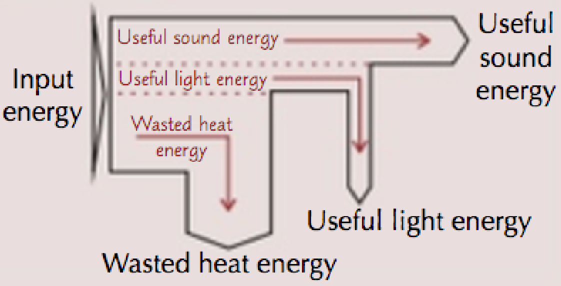
The **Thickness** of the **Arrow** Represents the **Amount** of **Energy**

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.

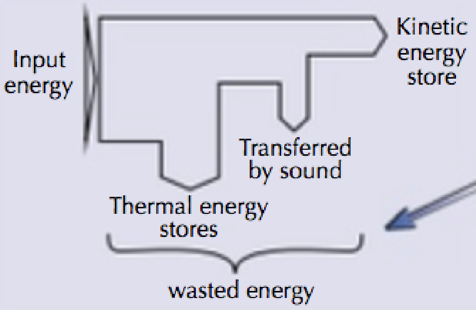
You can have either a little sketch or a properly detailed diagram where the width of each arrow is proportional to the number of joules it represents.

Example — TV:



Example — Sankey Diagram for a **Simple Motor**:

Here's the sketch version:



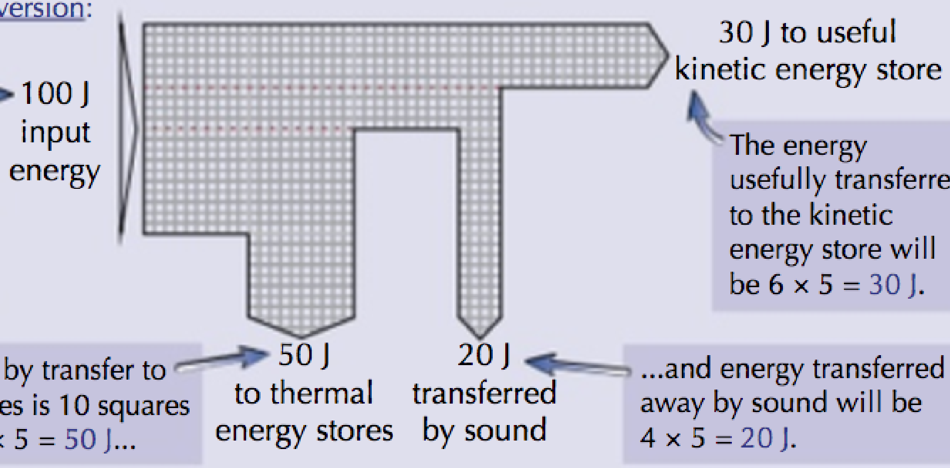
You don't know the actual amounts, but you can see that most of the energy is being wasted, and that it's mostly wasted as heat.

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).

Here's the detailed version:

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's 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 page 76).

Warm-Up & Exam Questions

You must be getting used to the routine by now — the warm-up questions get you, well, warmed up, and the exam questions give you some idea of what you'll have to cope with on the day.

Warm-Up Questions

1) What type of useful energy store is food?
2) State the principle of the conservation of energy.
3) Describe the energy transfers that take place when a ball is hit with a bat.

Exam Questions

1 This question is about energy transfers.

Copy and complete the table below.
For each scenario, state the energy store that energy is transferred away from.

Scenario	Energy Transferred From...
A skydiver falling from an aeroplane.	
A substance undergoing a nuclear reaction.	
A stretched spring returning to its original shape.	
A piece of burning coal.	

[3 marks]

2 Fan A transfers 20 J of energy per second away from its battery's chemical energy store. 8 J is transferred to the fan's kinetic energy stores, 11.5 J is transferred to the thermal energy stores of the fan's moving parts and the surroundings and 0.5 J is carried away by sound.

(a) Name the store that energy is usefully transferred to by fan A.

[1 mark]

(b) (i) State the equation linking percentage efficiency, useful energy output and total energy input.

[1 mark]

(ii) Calculate the percentage efficiency of fan A.

[2 marks]

(c) Fan B has an efficiency of 55% and usefully transfers 10 J of energy to its kinetic energy store each second.
Calculate how much energy is supplied to fan B per second.

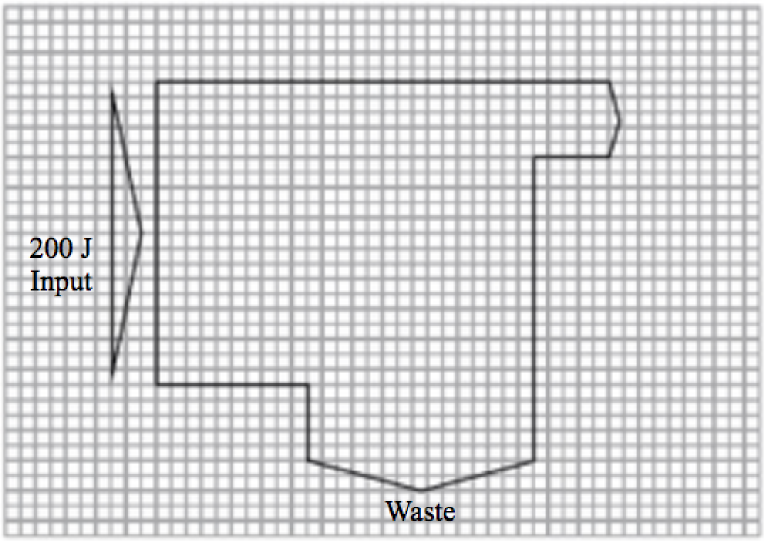
[3 marks]

(d) Each fan is powered by an identical battery. A student claims that the battery in fan B will go 'flat' quicker than in fan A because it transfers more energy to its kinetic store.
Do you agree or disagree? Explain your answer.

[1 mark]

Exam Questions

3 The manufacturer of a toy crane creates a Sankey diagram to show the energy transfers involved when the crane is in operation.



(a) Calculate the value represented by each small square.

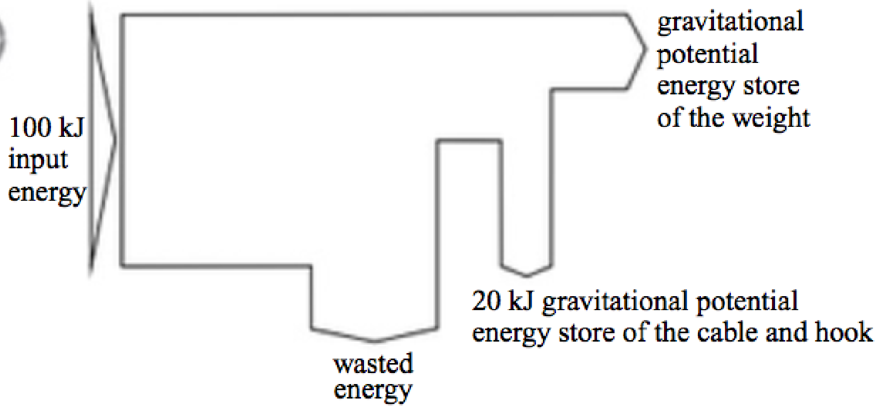
[1 mark]

(b) Calculate how much energy, in J, is transferred usefully by the toy crane for every 200 J of energy supplied.

[1 mark]

4 A winch uses a cable and a hook to lift a weight by winding the cable around a drum.

On the right is a Sankey diagram for the winch lifting a weight.



(a) Suggest **one** type of energy store that energy is transferred to when energy is wasted by the winch.

[1 mark]

(b) The winch wastes a total of 50 kJ. Calculate the energy, in kJ, transferred to the gravitational potential energy store of the weight by the winch.

[1 mark]

(c) The weight is released and falls to the ground. 1.5 kJ of energy is wastefully transferred to thermal energy stores and carried away by sound, due to air resistance acting on the weight during the fall.

Sketch and label a Sankey diagram to show the energy transfers that take place during the weight's fall.

[3 marks]

Conduction, Convection and Radiation

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 next page).

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.

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 page 55).

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 pages 84-85 for more on this.

Energy transfer by radiation happens constantly...

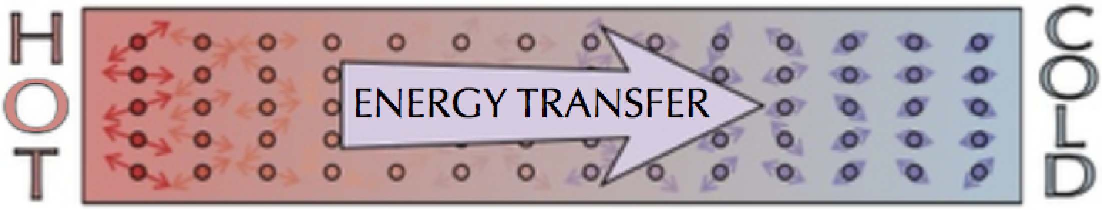
Conduction, convection and radiation are separate processes. But more than one of them can happen at once. So if you're asked to think about how thermal energy is being transferred away from an object, make sure you think about everything that might be going on, both in the object and in its surroundings.

Conduction, Convection and Radiation

There's more about heat transfer coming up on this page. It's all about conduction (which happens mainly in solids) and convection (which only happens in liquids and gases).

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.



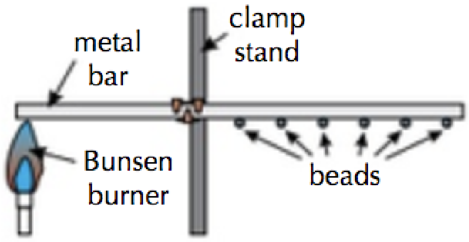
Thermal conduction is the process where vibrating particles transfer energy from their kinetic energy store to the kinetic energy stores of neighbouring particles.

This process continues throughout the solid and gradually some of the energy is passed all the way through, 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. 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.



Convection of Heat — Liquids and Gases Only

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

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

2) This is how immersion heaters in kettles, hot water tanks and convector heaters work.
3) Convection simply can't happen in solids because the particles can't move (apart from vibrating — see page 103).

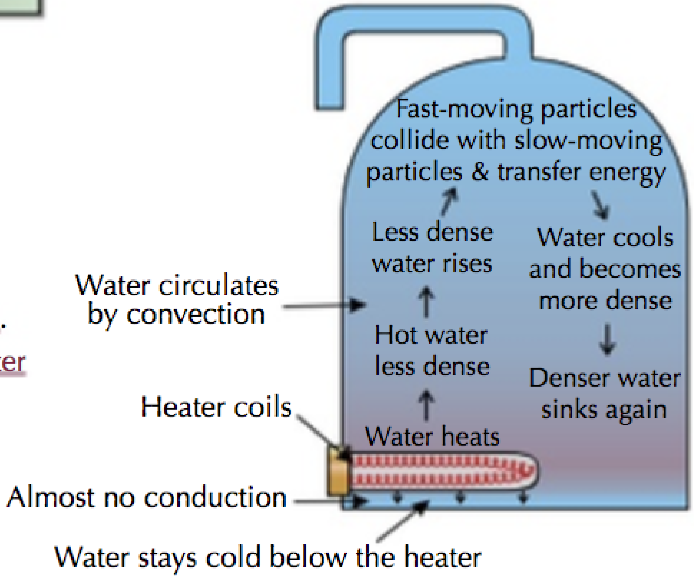
Conduction, Convection and Radiation

Take a deep breath — here are some examples of convection in action...

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, the colder water sinks 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.
6) 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.



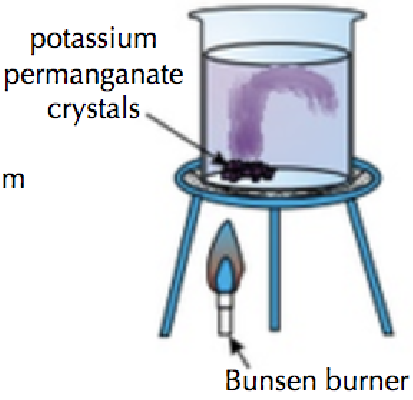
Convection is most efficient in round-ish or square-ish containers, because they allow the convection currents to work best. Shallow, wide containers or tall, thin ones just don't work quite so well.

CONVECTION CURRENTS are all about CHANGES IN DENSITY.

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.



In convection, particles move from hotter areas to cooler areas...

...so the particles move, taking their energy with them. Don't get this confused with conduction, where the particles can't move from their fixed positions, but vibrate to transfer energy to neighbouring particles. Have a flick back to the previous page if you need to remind yourself about conduction.

Energy Transfers by Heating

Energy transfer can be a problem if you're trying to keep the energy you've got. 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.

For example, this building has cavity wall insulation — the foam layer traps air between the inner and outer walls.

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).

Some substances are better thermal conductors than others...

Denser materials (see page 101) are usually better conductors than less dense materials. It's easy to see why — particles that are right next to each other can pass energy between their kinetic energy stores far more effectively than particles that are far apart. For example, water is a much better thermal conductor than air.

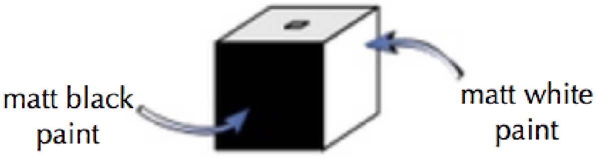
Energy Transfers by Heating

PRACTICAL

Here comes another practical that you can do to investigate energy transfer by heating — this one focuses on radiation, and involves a fun piece of kit called a Leslie cube.

You Can Investigate **Emission of IR 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:



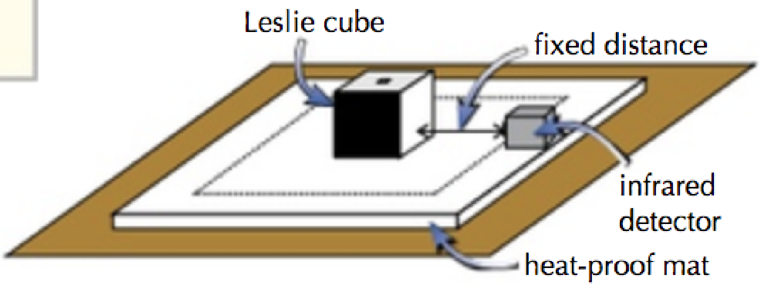
1) Place an empty Leslie cube on a heat-proof mat.

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 reliable (see page 156).

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 too.

You can also investigate how the absorption of IR radiation depends on the surface absorbing it. One way is to stick ball bearings to pieces of two different materials using wax. Then place the backs of the materials at an equal distance from a heat source and see which ball bearing falls off first.

PRACTICAL TIP

Carry out your practicals carefully...

...and that means both being careful when collecting data, and when dealing with any potential hazards. Watch out when you're pouring or carrying boiling water, and make sure any water or equipment has cooled down enough before you start handling it after your experiment is done.

Warm-Up & Exam Questions

Hopefully the last few pages have stuck, but there's only one way to check — and that's with some questions. Warm-up questions to get you started, and then exam questions to really get your teeth into.

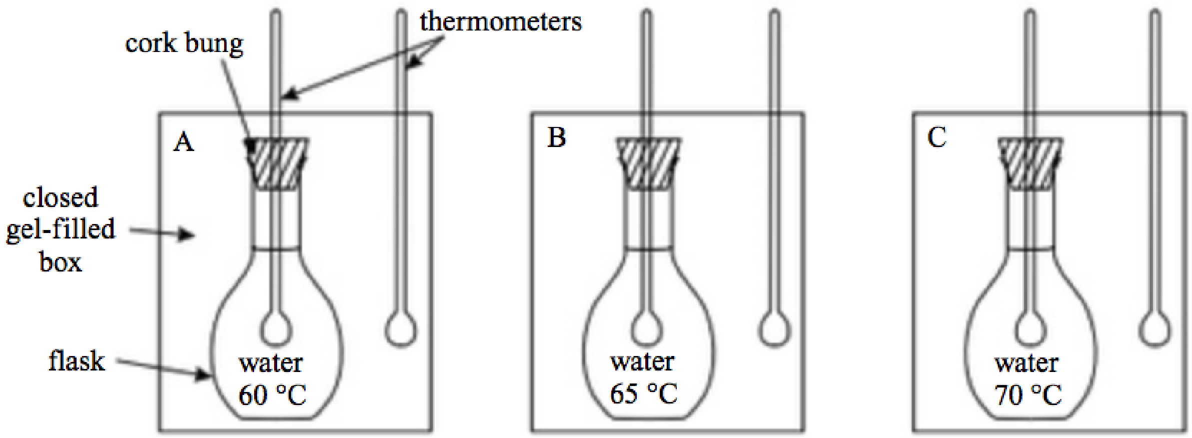
Warm-Up Questions

1) True or false? Thermal radiation can also be called ultraviolet radiation.
2) Explain how energy is transferred through a solid by conduction.
3) Why does convection only take place in liquids and gases?
4) Explain how an immersion heater works.

Exam Questions

1 Three flasks, each containing 100 ml of water, are placed in closed boxes filled with a clear gel at an initial temperature of 50 °C.
The water in each flask is at a different temperature, as shown.

Grade 4-6



a) Name **two** ways in which the flasks will transfer heat to the gel surrounding them.

[2 marks]

b) State which flask will transfer heat to the gel the fastest. Explain your answer.

[2 marks]

2 A homeowner is worried that her house is losing a lot of heat energy through its walls and windows. The outer walls of the house are made up of two layers of bricks separated by an air cavity.

Grade 4-6

(a) Which type of energy transfer does having an air gap in the wall help to reduce?

[1 mark]

(b) The homeowner is considering having cavity wall insulation installed.
Explain how this will help to reduce energy transfer by convection.

[1 mark]

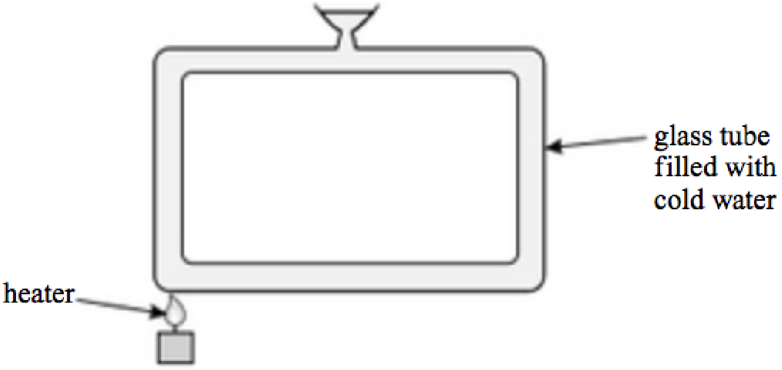
Exam Questions

3 Energy can be transferred by convection. Grade 6-7

(a) Give the state of matter in which convection cannot take place. Give a reason for your answer.

[2 marks]

(b) A student is carrying out an experiment in class to demonstrate convection.
She fills a rectangular glass tube with water and heats one of the bottom corners, as shown.



(i) Copy the diagram above and draw **two** arrows to show the movement of the water in the tube.

[1 mark]

(ii) Explain why the water in the tube moves in the way that you have shown in part (i).

[3 marks]

(c) Which of the following is **not** an example of convection?

☐ **A** the heating of a large room by a radiator

☐ **B** the heating of water in a kettle

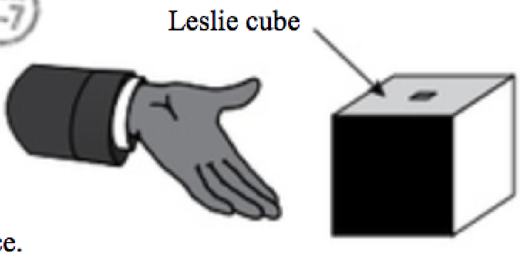
☐ **C** the transfer of energy by heating through a copper pan

☐ **D** hot air rising up a chimney

[1 mark]

PRACTICAL

4 A student uses a Leslie cube, shown in the diagram to the right, to investigate how different surfaces radiate energy. A Leslie cube is a hollow cube with faces that have differently textured and coloured surfaces. Grade 6-7



The student fills the cube with hot water and places his hand near to each surface.
He records how warm his hand feels in front of each surface.
The four sides of the cube are matt black, shiny black, matt white and shiny white.

(a) Predict which side the student's hand would feel warmest in front of.

[1 mark]

(b) Predict which side the student's hand would feel coolest in front of.

[1 mark]

(c) Suggest **one** way that the student could improve his method.

[1 mark]

Work

Work (like a lot of things) means something slightly different in Physics to what it means in everyday life...

'Work Done' is Just 'Energy Transferred'

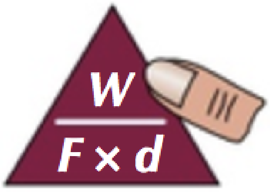
When a force moves an object through a distance, WORK IS DONE on the object and ENERGY IS TRANSFERRED.

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 (see page 74).
3) Whether energy is transferred usefully (e.g. lifting a load) or is wasted (see page 75), you can still say that work is done, because work done and energy transferred are the same thing.

> For example, 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 of the object and the surface due to the friction. This causes the temperature of the object and the surface to increase. (Like rubbing your hands together to warm them up.)

There's a Formula to Learn for Work Done:

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.

> Example: Some people drag an old tractor tyre 5 m over flat ground. They pull with a total force of 340 N. Find the work done.
>
> Answer: $W = F \times d$
> $= 340 \times 5 = 1700$ J

MATHS TIP

Doing work involves a force acting over a distance...

Whenever you use a formula in Physics, always make sure that the values you're putting in are in the right units. For example, when you're using the formula above, make sure that your force is in newtons and your distance is in metres — or the answer you get for work done won't be in joules.

Power

The more powerful a device is, the more energy it will transfer in a certain amount of time.

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.

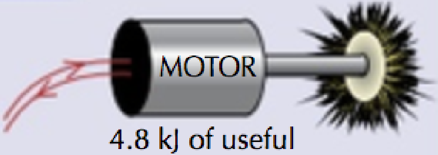
3) This is the formula for power:

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

4) The proper unit of power is the watt (W).
1 W = 1 J of energy transferred per second (J/s).

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

Answer: energy = 4.8 kJ = 4800 J
time = 2 minutes = 120 s
$P = W \div t$
$= 4800 \div 120 = 40$ W (or 40 J/s)



4.8 kJ of useful energy transferred in 2 minutes

A large power doesn't always mean a large force...

The power that a car has is often measured in a funny unit called horsepower. 1 horsepower is the rate at which energy is transferred when a horse raises a mass of 550 lb through a height of 1 ft in 1 second... I think I'd stick to watts if I were you. Anyway, make sure that you've learnt the formula for power.

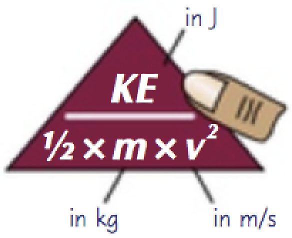
Kinetic and Potential Energy Stores

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:

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.

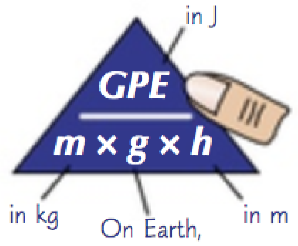
Answer: $KE = \frac{1}{2}mv^2 = \frac{1}{2} \times 2450 \times 38^2 = 1\,768\,900$ J

Raised Objects Store Energy in **G.P.E.** Stores

g.p.e. = gravitational potential energy

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 (see page 5).

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



On Earth, $g = 10$ m/s² (This is the same as 10 N/kg, since 1 m/s² = 1 N/kg.)

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 74.
4) In real life, air resistance acts against all falling objects (see page 16)— it causes some energy to be transferred to other energy stores, e.g. the thermal energy stores of the object and surroundings.

REVISION TIP

Greater height means more energy in G.P.E. stores...

If you're struggling to remember any of these formulas that you need to know, you could make up a handy mnemonic to help you. Like "kitten eats half my village square" for $KE = \frac{1}{2}mv^2$.

Warm-Up & Exam Questions

There were lots of definitions and equations to get to grips with on the last few pages.
Try these questions to see what you can remember.

Warm-Up Questions

1) What is meant by the work done by a force?
2) What's the formula linking power and work done?
3) State the equation linking kinetic energy, mass and speed.

Exam Questions

1 Which of these is the definition of power?

☐ **A** Power is the total work done by an object.

☐ **B** Power is the rate at which energy is transferred.

☐ **C** Power is the total energy transferred to an object.

☐ **D** Power is the minimum work done to an object to cause it to move.

[1 mark]

2 A woman pushes a 20 kg wheelbarrow 15 m along a flat path using a horizontal force of 50 N.

(a) (i) State the equation that links work done, force applied and distance moved in the direction of the force.

[1 mark]

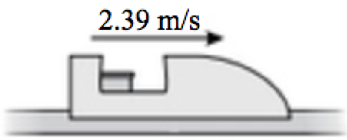
(ii) Calculate the work done by the woman, in J.

[2 marks]

(b) Work has to be done against the frictional forces acting on the wheel of the wheelbarrow. Explain the effect this has on the temperature of the wheel.

[2 marks]

3 A roller coaster cart with a mass of 105 kg is rolling along a horizontal track at 2.39 m/s.



(a) Calculate the energy in the kinetic energy store of the cart, in J.

[3 marks]

(b) The cart reaches a downhill slope in the track with a vertical height of 20.2 m. It rolls down the slope with no driving force other than gravity.

(i) Calculate the energy lost from the gravitational potential energy store of the cart as it rolls down the slope, in J.

[3 marks]

(ii) Assuming no friction acts against the cart, explain what happens to the energy that is lost from the gravitational potential energy store.

[1 mark]

Non-Renewable Energy and Power Stations

There are different types of energy resource, but they fit into two types: renewable and non-renewable.

Non-Renewable Energy Resources Will Run Out One Day

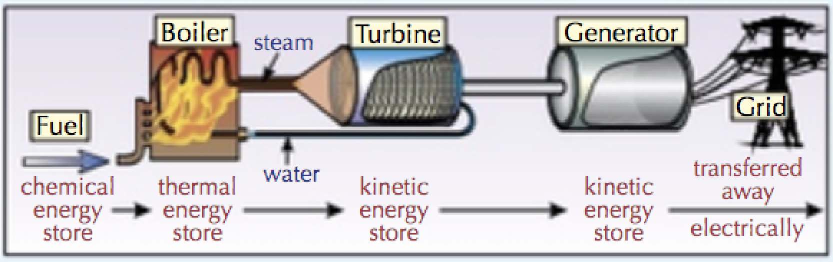
The non-renewables are the three fossil fuels and nuclear:

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

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, which is a bit different in nuclear power stations — see page 93):



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 p.121). 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 93-97), 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

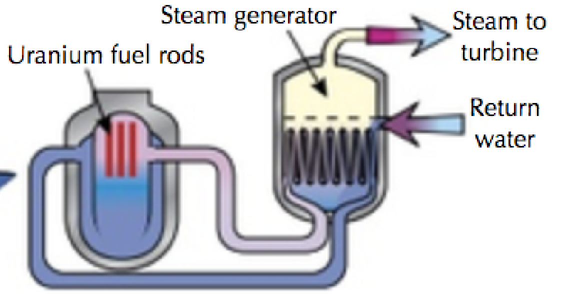
1) All three fossil fuels release carbon dioxide (CO_2) into the atmosphere when burned in power stations. All this CO_2 contributes to global warming and climate change.
2) Burning coal and oil also releases sulfur dioxide (SO_2), which causes acid rain. Acid rain can harm trees and soils and can have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

Nuclear and Geothermal Energy

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

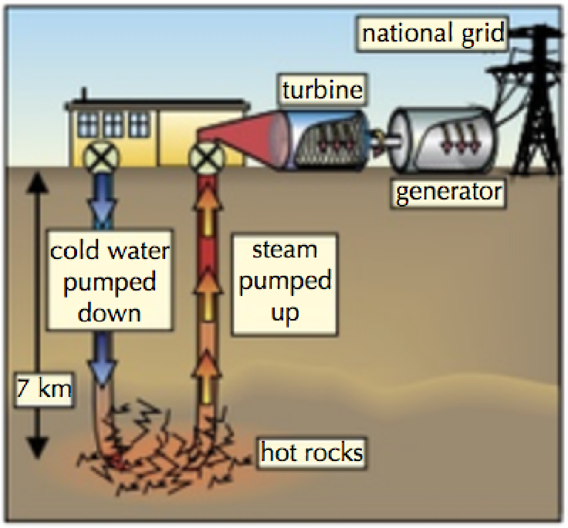
Nuclear Reactors are Just Fancy Boilers

1) A nuclear power station is mostly the same as the one on page 92. The difference is that nuclear fission (see page 139), 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).

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 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).

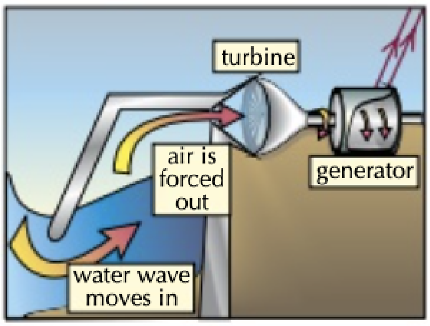
Wind and Wave Energy

A nice, cool breeze and waves lapping against the shore... two more ways of generating electricity.

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. Some people think 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 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.
7) And although the wind is free, it's expensive to set up a wind farm, especially out at sea.

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.
7) Wave power is unlikely to provide energy on a large scale but it can be very useful on small islands.

EXAM TIP

More renewable energy resources to learn

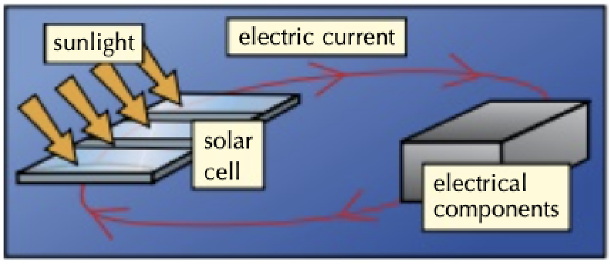
For the exam, you'll need to be able to describe the energy transfers involved in all these methods of generating electricity, as well as the ones described over the next few pages. You'll also need to be able to write about the advantages and disadvantages of each method.

Solar Energy

Energy from the Sun can be used to generate electricity too, or harnessed directly for heating.

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 page 30).



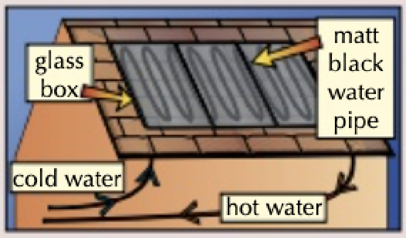
2) The Sun provides a renewable energy resource — it won't run out (not for 5 billion years anyway).
3) Solar cells are very expensive initially, but after that the energy is free and running costs are almost nil. And there's no pollution produced while using them (although some is produced during their 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 can be enormous compared with the value of the electricity generated.
6) 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.
7) 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

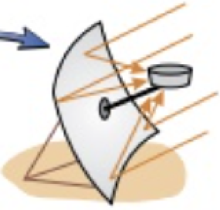
Solar water heating panels are more simple than solar cells — they're basically just black water pipes inside a glass box. The glass lets energy from the Sun in, which is then absorbed by the black pipes and heats up the water.

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.

Generating Electricity Using Water

Water, water, everywhere. Perfect for generating electricity.

Tidal Barrages Generate Energy When the **Tide** Goes **In** and **Out**

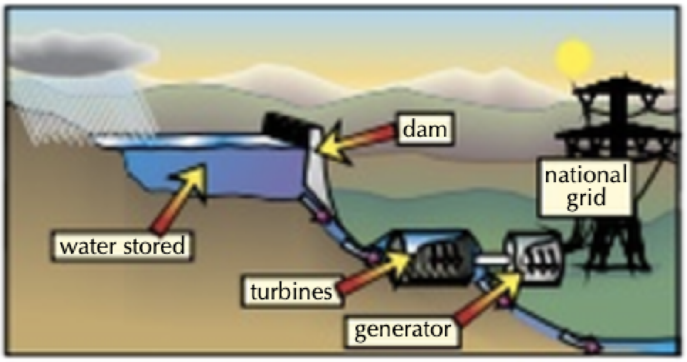
1) Tidal barrages are big dams built across river estuaries, with turbines in them. As the tide comes in it fills up the estuary to a height of several metres. This water can then be allowed out through turbines at a controlled speed. It also drives the turbines on the way in.

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.

Paper 2

Paper 2

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. This 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.

Renewable AND reliable, but a big impact on the local environment...

Unlike wind, wave and solar energy, tidal barrages and hydroelectric power installations are able to generate a fairly constant supply of electricity (or even vary their output to match demand). However, they can cause lasting change to the appearance of the surrounding area and to the wildlife that lives there.

Generating Electricity Using Water

Nearly at the end of all this energy resources stuff now. Just one more page...

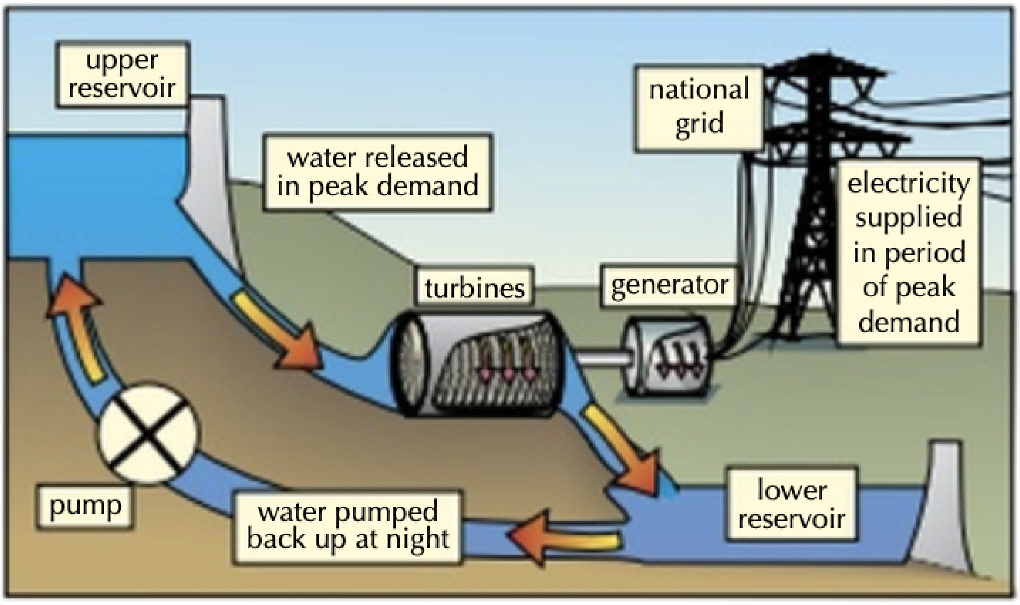
Pumped Storage Gives Extra Supply Just When it's Needed

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.

Here's **How** it **Works**...

1) In pumped storage, 'spare' night-time electricity is used to pump water up to a higher reservoir.

2) 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.



It's a really clever idea — the 'spare' electricity is used to transfer energy back to the water's gravitational potential energy stores, so that it can generate more electricity when it is needed by flowing through the dam.

Pumped storage doesn't generate power — it stores it

There tend to be surges in demand for electricity at certain times — for example, there's often a surge in demand when it gets to half-time in a big football match, as everyone switches their kettles on. Clever people at the National Grid have to try to predict what electricity we'll need and when. They can then employ pumped storage facilities, like the one at Dinorwig in Wales, to try to meet demand.

Warm-Up & Exam Questions

It's very nearly the end of this section. But don't shed a tear — try these questions instead.

Warm-Up Questions

1) How does burning coal contribute to acid rain? Give one problem caused by acid rain.
2) Give two advantages of using solar energy to generate electricity instead of fossil fuels.
3) What does it mean if an energy resource is 'renewable'?

Exam Questions

PAPER 2

1 Which of the following energy sources is a renewable energy source?

☐ **A** coal ☐ **B** nuclear ☐ **C** wind ☐ **D** oil

[1 mark]

PAPER 2

2 Electricity can be generated using wind and geothermal power.

(a) (i) The diagram below shows the transfers of energy during the generation of electricity using geothermal power. Copy and complete the diagram to show the types of energy store involved in the energy transfers.

.... → .... → ....

energy store of hot rocks — energy store of water — energy stores of turbine and generator

[3 marks]

(ii) Give **one** advantage and **one** disadvantage of generating electricity using geothermal resources.

[2 marks]

(b) Give **one** advantage and **one** disadvantage of generating electricity using wind.

[2 marks]

PAPER 2

3 In some coastal regions, electricity is generated from waves using wave converters.

(a) Which of the following statements about wave converters is true?

☐ **A** They generate electricity all the time.

☐ **B** The initial costs of wave converters are low.

☐ **C** They produce pollution when generating electricity.

☐ **D** They can be hazardous to boats.

[1 mark]

(b) Describe the energy transfer that occurs in a wave converter when it is used to generate electricity.

[1 mark]

Exam Questions

PAPER 2

4 In a nuclear power station, water is heated to produce steam.

(a) Describe the energy transfer(s) that occur in a nuclear power station to produce the steam.

[1 mark]

(b) (i) One argument for building more nuclear power stations is that generating electricity from nuclear fuel does not directly contribute to global warming. Explain why this is the case.

[1 mark]

(ii) Give **two** ways in which generating nuclear power can harm the environment.

[2 marks]

PAPER 2

5 Energy from the Sun is used in different ways.

(a) Name **one** type of device that uses energy from the Sun to directly generate electricity.

[1 mark]

(b) Electricity generated from the Sun's energy can be used to heat water in a home.
Name and describe **one** other way the Sun's energy can be used to heat water in a home.

[2 marks]

(c) Give **two** reasons why electricity generated from the Sun is rarely supplied to the national grid.

[2 marks]

PAPER 2

6 Water can be used in many ways to generate electricity. In some countries, electricity is generated using hydroelectric dams. Water is held back behind the dam before being allowed to flow out through turbines to produce electricity.

(a) Describe the energy transfers involved when water flowing through the turbines is used to produce electricity.

[3 marks]

(b) Hydroelectric power stations don't produce any carbon dioxide when generating electricity.
Give **two** ways that using hydroelectric power stations to generate electricity damages the environment.

[2 marks]

(c) In some hydroelectric power stations, energy is used to pump water back into the reservoir during times of low electricity demand. Give the name of this type of system.

[1 mark]

(d) Sea tides can also be used to generate electricity using tidal barrages.
Give **two** advantages of generating electricity using tidal barrages.

[2 marks]

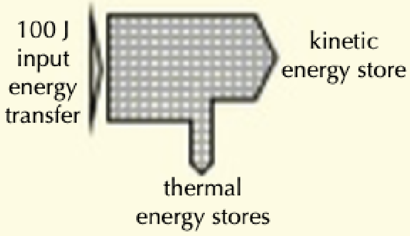
Revision Questions for Section 4

Phew, that was a fairly hefty section. Time to check you've taken it all in — I hope you're feeling energised...

- 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.74-78) ☐

1) Name eight types of energy store. ☐
2) *What is the percentage 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? ☐
3) Describe the energy transfers that occur in a battery-powered toy car. ☐
4) *The Sankey diagram below shows how energy is transferred in a catapult.



a) How much energy is transferred to the kinetic energy store?
b) How much energy is wasted?
c) What is the percentage efficiency of the catapult? ☐

Energy Transfers by Heating (p.81-85) ☐

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

Calculating Energy and Power (p.88-90) ☐

8) *A dog dragged 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? ☐
9) *An electric motor uses 540 kJ of electrical energy in 4.5 minutes. What is its power consumption? ☐
10) *Find the energy in the kinetic energy store of a 78 kg sheep moving at 2.3 m/s. ☐
11) What happens to the amount of energy in an object's gravitational potential energy store when it is lifted above the ground? ☐
12) Write down the formula used to find the energy in an object's gravitational potential energy store. ☐

Energy Resources (p.92-97) ☐

13) List four different types of renewable energy resource. ☐
14) Describe the energy transfers that take place when burning fossil fuels to generate electricity in a typical power station. ☐
15) State two advantages and two disadvantages of using fossil fuels to generate electricity. ☐
16) Describe the energy transfers that take place when a tidal barrage is used to generate electricity. ☐

*Answers on page 211.

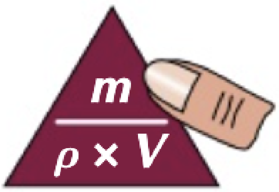
Density

Density tells you how much mass is packed into a given volume of space. You need to be able to work it out, as well as carry out practicals to work out the densities of liquids and solids. Lucky you.

Density is **Mass** per Unit **Volume**

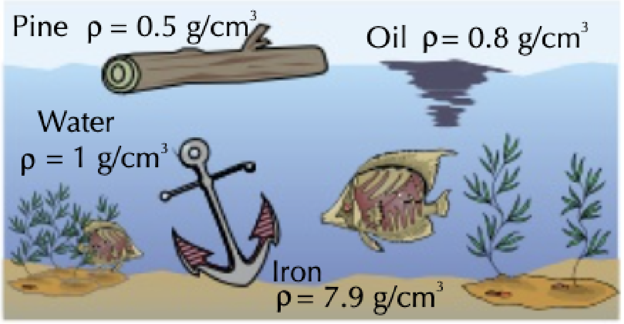
Density is a measure of the 'compactness' (for want of a better word) of a substance. It relates the mass of a substance to how much space it takes up.

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



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

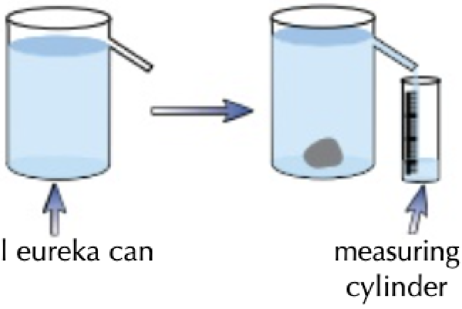
1) The units of density are g/cm^3 or kg/m^3. $1\ g/cm^3 = 1000\ kg/m^3$
2) The density of an object depends on what it's made of. Density doesn't vary with size or shape.
3) The average density of an object determines whether it floats or sinks — a solid object will float on a fluid if it has a lower 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.



A dense material has a lot of mass in a small volume

Dense materials tend to feel really heavy for their size. If you look at the formula for finding the density of an object, you'll see that a dense material must have a big mass in comparison to its volume.

Pressure

You probably hear about pressure a fair bit in everyday life, but (as always) there are some lovely equations to describe it in Physics. Better get your calculator out...

Pressure is Force per Unit Area

1) Pressure is a measure of the force being applied to the surface of something.
2) It relates how much force is being applied to an object (in N) to the area that it is applied over (in m^2).

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

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

3) Pressure is usually measured in pascals, Pa (or kilopascals, kPa). 1 pascal is defined as 1 N/m^2.

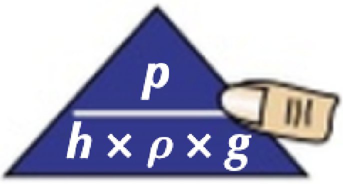
1 kPa = 1000 Pa

- The same force being applied over a larger area creates a lower pressure.
- In gases and liquids at rest, the pressure at any point acts equally in all directions.
- In gases and liquids, 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

1) Pressure difference is the difference in pressure between two points in a liquid or gas.
2) It depends on the height difference (in m), and the density (in kg/m^3) of the substance.
3) Gravity has an effect too — g is the gravitational field strength, which is around 10 m/s^2.

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



MATHS TIP

Formula triangles can make using equations easier

Formula triangles can be a handy way of helping you rearrange equations. Just cover up the variable you're interested in, and then the positions of the other variables will show you how you need to write the equation. As long as you can remember the triangle, it makes life easier.

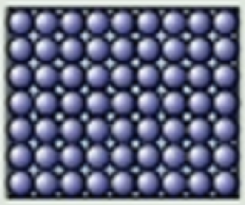
Changes of State

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

Kinetic Theory Can Explain the Three States of Matter

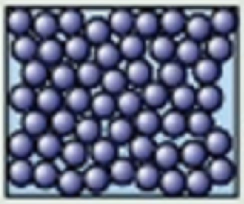
1) The three states of matter are solid (e.g. ice), liquid (e.g. water) and gas (e.g. water vapour). The particles of a substance in each state are the same — only the arrangement and energy of the particles are different.

Solids



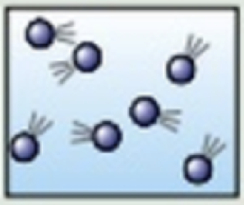
Strong forces of attraction hold the particles close together in a fixed, regular arrangement. The particles don't have much energy so they can only vibrate about their fixed positions.

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. 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 boiling point of a substance 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.

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

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.

Paper 2

Evaporation

There are two processes by which a liquid can turn into a gas — boiling and evaporation.
You've come across boiling already, so here's how evaporation works:

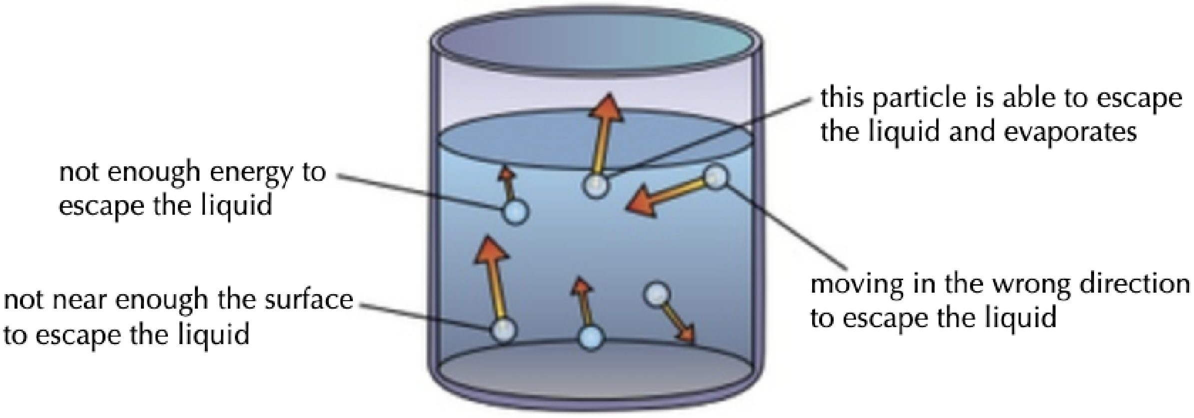
Evaporation is a Special Example of **Changing States**

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.

Evaporation depends on kinetic energy

Particles in a liquid need to have a high kinetic energy to evaporate. When a particle evaporates, it takes its kinetic energy with it — so the average energy in the kinetic stores of the particles in the liquid decreases.

Warm-Up & Exam Questions

It's time again to test what you've learnt from the last few pages. Have a go at these...

Warm-Up Questions

1) Describe how you would measure the volume of an irregularly shaped object.
2) What basic unit is pressure measured in?
3) How is the energy in a substance's thermal energy store held?
4) State the conditions necessary for particles near the surface of a liquid to escape by evaporation.

Exam Questions

1 A company that manufactures a water-resistant digital watch tests the watch under high pressure in salt water. They only recommend it is used underwater if the pressure difference from the surface is 245 kPa or less.

Grade 6-7

(a) State the equation linking pressure difference, height, density and gravitational field strength (*g*).

[1 mark]

(b) (i) The mass of a 0.5000 m^3 volume of salt water is 514.0 kg. Calculate the density of the salt water in kg/m^3.

[2 marks]

(ii) Calculate the maximum depth in m from the surface of the salt water that the watch can be used at. Gravitational field strength, $g = 10\ m/s^2$.

[3 marks]

PAPER 2

2 Substances can exist in different states of matter.

Grade 6-7

(a) (i) Describe the arrangement and movement of the particles in a solid.

[2 marks]

(ii) Give the name of the state of matter that possesses the **highest** average energy per particle.

[1 mark]

(b) If a substance is heated to a certain temperature it can change from a solid to a liquid.

(i) Give the name of this process.

[1 mark]

(ii) Explain why the temperature of the substance does not increase during this process.

[2 marks]

(c) If a liquid is heated to a certain temperature it starts to boil and become a gas.

(i) Name the other process by which a liquid starts to become a gas. Explain how it is different to boiling.

[3 marks]

(ii) Explain why the remaining liquid cools down when a liquid starts to turn into a gas by the process named in part (i).

[3 marks]

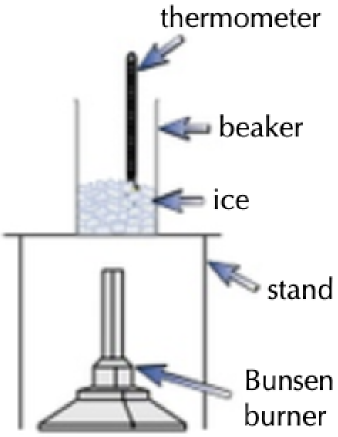
PRACTICAL Temperature and Particle Theory

Here's another experiment that you might do in class, or be asked about in your exams.
Make sure you know the method, and can remember the shape of the graph you'd expect to obtain.

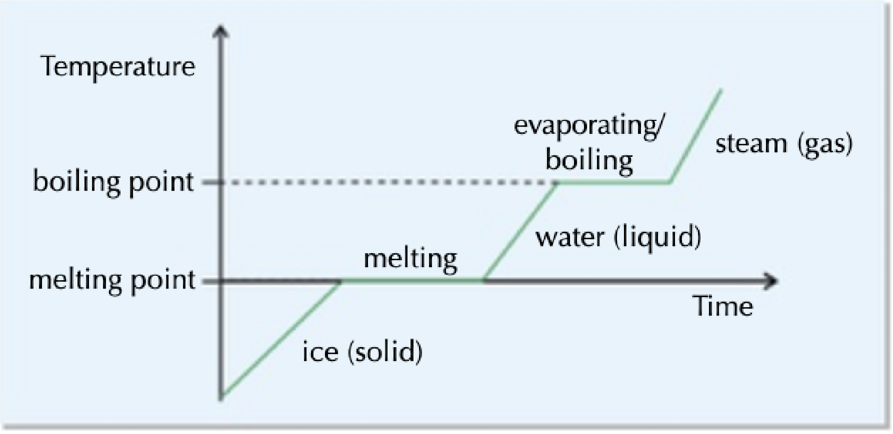
You Can Obtain a **Temperature-Time Graph** for **Water**

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

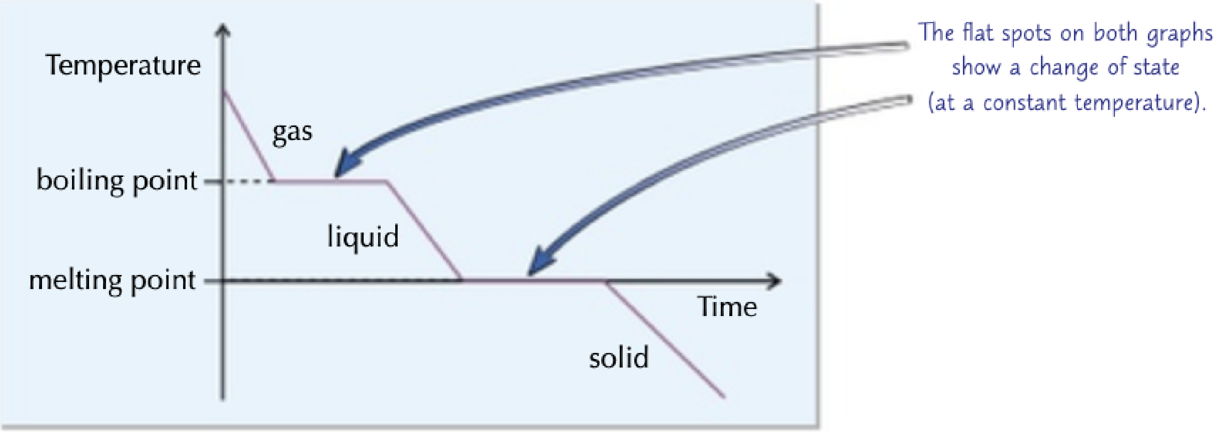
1) Fill a beaker with crushed ice. Place a thermometer into the beaker and record the temperature of the ice.
2) Using the Bunsen burner, gradually heat the beaker full of ice.
3) Every twenty seconds, record the temperature and the current state of the ice (e.g. partially melted, completely melted). 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).

The temperature of a substance is constant as it changes state...

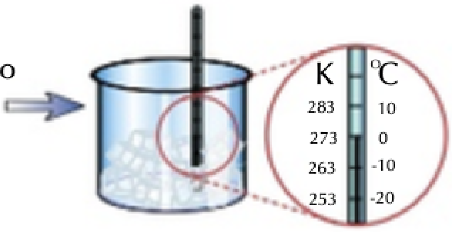
Remember: energy isn't being transferred to the particles' kinetic energy stores during a change of state, so the temperature of the substance stays the same and you get flat spots on a temperature-time graph.

Temperature and Particle Theory

You've probably heard of Celsius and Fahrenheit, but did you know there's yet another temperature scale? This one's often used by scientists as well, so read on to find out more...

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, all you need to do is 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 — you just write K (not °K).

Energy in Particles' Kinetic 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 $\frac{1}{2}mv^2$, as you saw on page 90.

273 is the magic number...

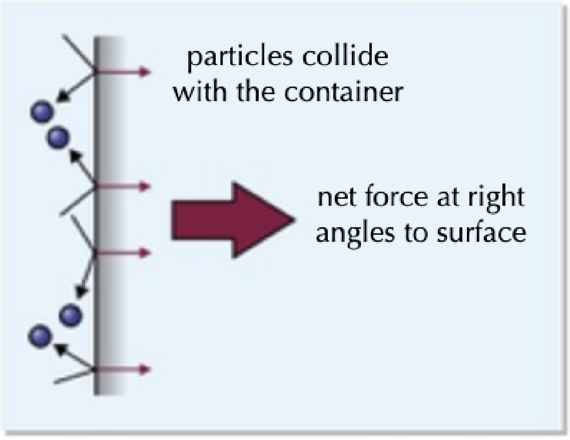
Doubling the temperature of a substance in Celsius doesn't double the energy in its particles' kinetic energy stores — that's only true for the Kelvin scale. So always check the scale that's being used for temperature.

Particle Theory and Pressure in Gases

Particle theory helps explain how temperature, pressure, volume and the energy in kinetic stores are related.

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 definitely aren'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.

Increasing the Temperature Increases the Pressure

1) If you heat a gas, the particles move faster and have more energy in their kinetic stores.
2) This increase in energy means the particles hit the container walls harder and more frequently, resulting in a larger force, creating more pressure.
3) In fact, temperature (in K) and pressure are proportional — double the temperature of a fixed amount of gas, and you double the pressure.

Increasing the Volume Decreases the Pressure

1) If you put the same fixed amount of gas in a bigger container, the pressure will decrease, because there'll be fewer collisions between the gas particles and the container's walls.
2) 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.

The pressure equation is simple to apply to gas pressure

Gas pressure is the amount of force exerted by the gas particles per unit area of the container wall that they're colliding with. It's 'force divided by area', just like it would be for any other type of pressure.

Particle Theory and Pressure in Gases

These equations are basically the maths-y way of describing what you learnt on the previous page...

At Constant Temperature "pV = Constant"

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

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.

Answer: $p_1V_1 = p_2V_2$, so $250 \times 300 = p_2 \times 175$

$p_2 = (250 \times 300) \div 175 = 429$ kPa (to 3 s.f.)

At Constant Volume "p/T = Constant"

In a sealed container (i.e. at 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: 30 litres of gas are placed in a sealed container. The gas is at a pressure of 100 kPa and a temperature of 290 K. Find the new pressure if the temperature is increased to 315 K.

Answer: $p_1/T_1 = p_2/T_2$, so $100 \div 290 = p_2 \div 315$

$p_2 = 315 \times (100 \div 290) = 109$ kPa (to 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).

EXAM TIP

You can use the equations sheet to help jog your memory

There are lots of formulas in IGCSE Physics. You'll need to know most of them off by heart, but some of the trickier ones will be given to you on an equations sheet in the exams. So it's worth getting to know what is on the equations sheet and what isn't — there's a copy of it on p.165.

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...

Paper 2

Paper 2

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)

The symbol 'Δ' is Greek letter delta. Δ just means 'change in'.

Example: Calculate the change in temperature when 12 600 J of energy is transferred to the thermal energy stores of 0.5 kg of water. The specific heat capacity of water is 4200 J/kg °C.

Answer: $\Delta Q = m \times c \times \Delta T$,

so $\Delta T = \Delta Q \div (m \times c)$

$= 12\,600 \div (0.5 \times 4200) = 6$ °C

REVISION TIP

Specific heat capacity = how hard it is to heat something up

The equation relating energy, mass, specific heat capacity and temperature is quite a tricky one. So get plenty of practice at using it — including rearranging it and checking that all your data is in the right units. That way you'll be more confident if you get a question on it in your exam.

Specific Heat Capacity

PRACTICAL

You can use the practical on this page to find the specific heat capacity of a material...

Paper 2

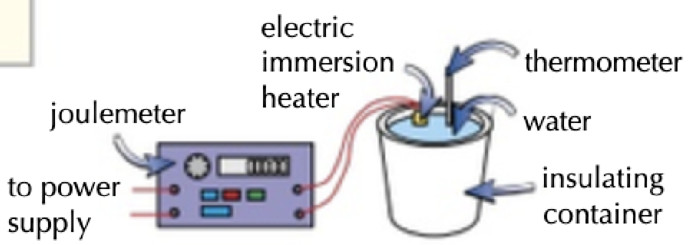
You can Find the **Specific Heat Capacity** of a **Liquid...**

You can use this experiment to find the specific heat capacity of water — or any liquid for that matter. You should use a thermally insulated container for this experiment to reduce the amount of energy that's transferred to the surroundings.

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.

You could use a voltmeter and ammeter instead of a joulemeter. Time how long the heater was on for, then calculate the energy supplied using the equation energy transferred = current × voltage × time (see page 43).

6) You can then calculate the specific heat capacity of the water by rearranging the equation $\Delta Q = m \times c \times \Delta T$ 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.

...or of a **Solid**

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.

Paper 2

PRACTICAL TIP

Think about how you could improve your experiments...

You need to be able to evaluate the method used for an investigation and suggest improvements to make the results more accurate. For example, if you saw a method for this practical using a beaker to hold the liquid, you could suggest changing it to a thermally insulated container.

Warm-Up & Exam Questions

You know the drill by now — time to put all the lovely information you've just absorbed to good use.

Warm-Up Questions

1) The temperature in kelvins of a certain volume of air increases by a factor of three. How will the kinetic energy of the air particles change, and by what factor?
2) Use particle theory to explain how gas particles create pressure in a sealed container.
3) What is meant by the specific heat capacity of a substance?

Exam Questions

1 The Kelvin scale and the Celsius scale are two scales that can be used to measure temperature. Grade 4-6

(a) (i) A gas is cooled. Describe what effect this has on the average speed of its particles.

[1 mark]

(ii) Explain why there is a minimum possible temperature that any substance can reach, known as the absolute zero of temperature.

[2 marks]

(iii) Give the numerical value of the absolute zero of temperature in degrees Celsius.

[1 mark]

(b) Temperature can be converted between the Kelvin and Celsius scales.

(i) Convert 10 K into °C.

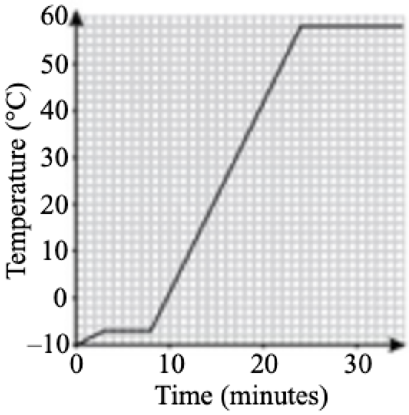
[1 mark]

(ii) Convert 631 °C into K.

[1 mark]

PAPER 2

2 The graph below shows the temperature of a substance against time as it is heated. Grade 4-6



(a) Describe what is happening during the period 3-8 minutes from the beginning of heating.

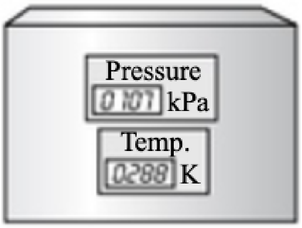
[1 mark]

(b) Give the melting and boiling points of the substance.

[2 marks]

Exam Questions

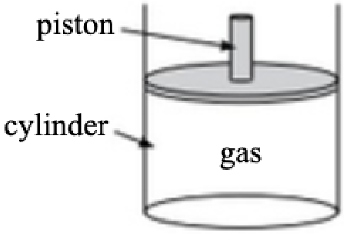
3 A sealed container with a fixed volume is fitted with internal temperature and pressure gauges. The gauges show that the temperature is 288 K and the pressure is 107 kPa inside the container. Grade 6-7



The container is heated so that the temperature of the gas inside it becomes 405 K. Calculate the pressure that will be shown on the pressure gauge.

[3 marks]

4 A cylinder sealed with a piston contains 0.014 m^3 of gas at a pressure of 98 kPa. Grade 7-9



(a) (i) The piston is squeezed in and the volume containing the gas decreases. State the effect on the gas pressure inside the cylinder. Explain your answer in terms of particle theory.

[3 marks]

(ii) The gas is compressed to a volume of 0.013 m^3. The temperature of the gas remains constant. Calculate the pressure inside the cylinder after the compression.

[3 marks]

(b) The cylinder is heated while the piston remains in place to keep its volume constant. State and explain what happens to the pressure inside the cylinder.

[3 marks]

PAPER 2 **PRACTICAL**

5 A student uses the equipment listed below to investigate the specific heat capacity of different liquids. Grade 7-9

- Insulated flask
- Thermometer
- Mass balance
- Power supply
- Joulemeter
- Immersion heater

Describe how the student could use this apparatus to calculate the specific heat capacity of a liquid.

[5 marks]

Revision Questions for Section 5

Section 5, over and out — time to put yourself to the test and find out how much you really know.

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

Density and Pressure (p.101-102) ☑

1) What is the relationship between the density, mass and volume of a substance? ☑
2) *If the density of water = 1000 kg/m^3, calculate the volume in m^3 of 2 kg of water. ☑
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? ☑

Changes of State (p.103-104) ☑

6) Describe how the particles are arranged and move in:
   a) a liquid, b) a gas. ☑
7) Explain what happens to particles in a substance during:
   a) melting, b) boiling, c) evaporation. ☑

Temperature, Pressure and Particle Theory (p.106-109) ☑

8) 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. ☑
9) On which temperature scale is the numerical value of 'absolute zero' actually equal to 0? ☑
10) How does the temperature of a gas in kelvins relate to the energy in the kinetic energy stores of its particles? ☑
11) What happens to the pressure of a gas in a sealed container if you increase the temperature? ☑
12) *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)? ☑
13) *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.110-111) ☑

14) What equation relates energy, mass, specific heat capacity and temperature? ☑
15) *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. ☑
16) Describe an experiment that can be used to find the specific heat capacity of a solid. ☑

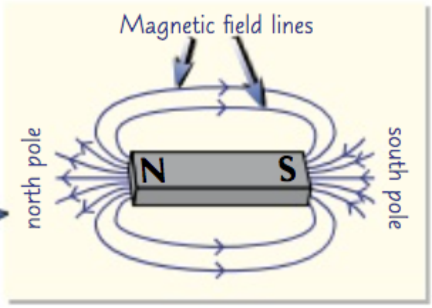
*Answers on page 212.

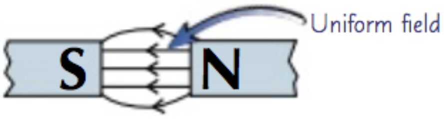
Magnets and Magnetic Fields

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.





You Can See Magnetic Field Patterns Using Compasses

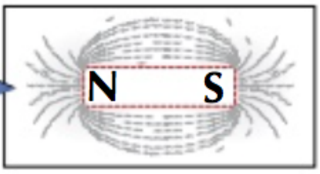
PRACTICAL

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.

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).

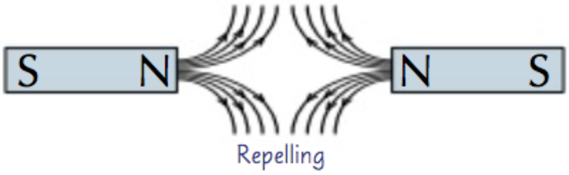
You shouldn't put the compasses too close to each other. Compasses also produce magnetic fields — you need to make sure you're measuring the field of the magnet rather than the compasses nearby.

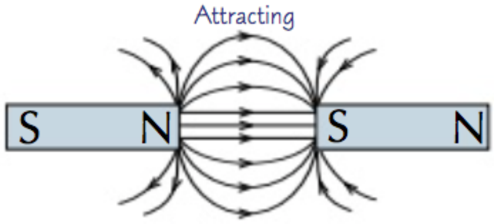
3) You could also use iron filings to see magnetic field patterns. Just put the magnet(s) under a piece of paper, scatter the iron filings on top, and tap the paper until the iron filings form a clear pattern.



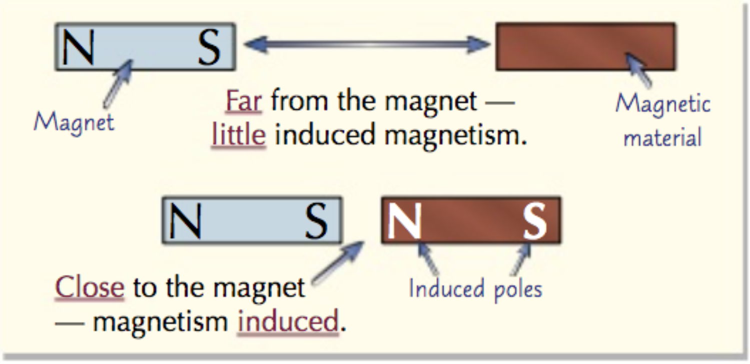
Magnetism Can Be Induced

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.



Far from the magnet — little induced magnetism.

Close to the magnet — magnetism induced.

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.

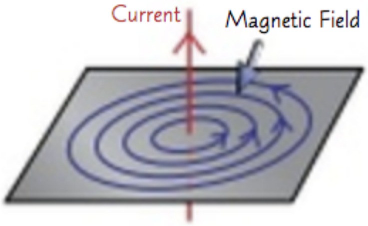
A Current-Carrying Wire Creates a Magnetic Field

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.

Paper 2

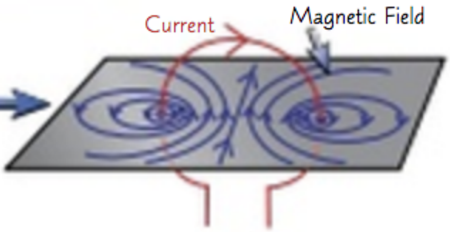
The Magnetic Field Around a Straight Wire

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.

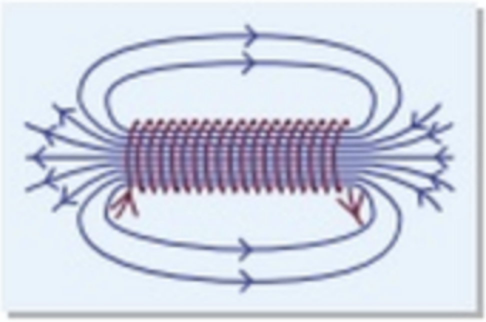


The Magnetic Field Around a Flat Circular Coil

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.



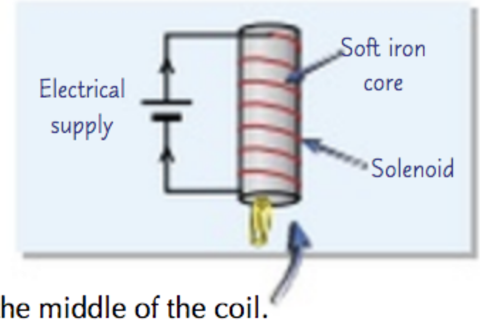
The Magnetic Field Around a Solenoid



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 (see page 64) because of this property — it needs to magnetise and demagnetise 50 times a second (mains electricity in the UK runs at 50 Hz).
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.



The Motor Effect

The motor effect happens when you put a current-carrying wire in a magnetic field. Read on for more...

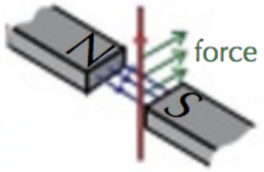
A Current in a Magnetic Field Experiences a Force

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.

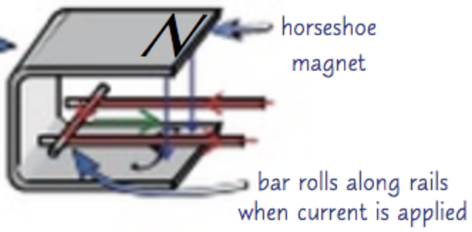
This is because charged particles (e.g. electrons in a current) moving through a magnetic field will experience a force, as long as they're not moving parallel to the field lines.

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.



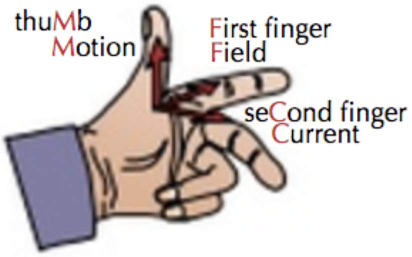
2) The force always acts in the same direction relative to the magnetic field of the magnets and the direction of the current in the wire.
3) A good way of showing the direction of the force is to apply a current to a set of rails inside a horseshoe magnet. A bar is placed on the rails, which completes the circuit. This generates a force that rolls the bar along the rails.



4) The magnitude (strength) of the force increases with the strength of the magnetic field. The force also increases with the amount of current passing through the conductor.
5) 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 this wire?

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

2) Fleming's LHR.

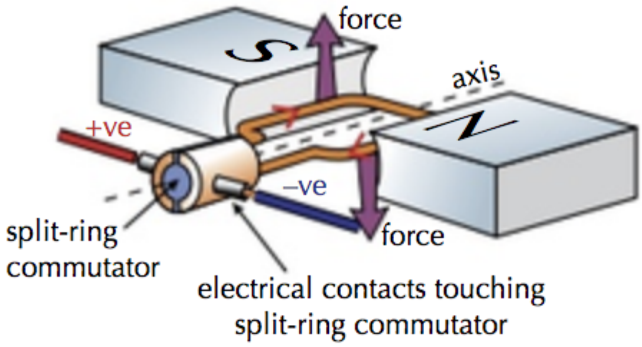
3) Draw in direction of force (motion).

Electric Motors and Loudspeakers

Electric motors use the motor effect to get them moving (and to keep them moving).

A Simple D.C. **Electric Motor**

Four factors that will speed it up:
1) More current
2) More turns on the coil
3) Stronger magnetic field
4) A soft iron core in the coil

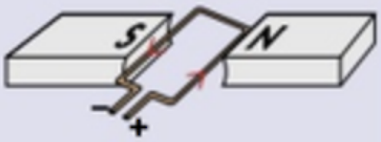


1) The diagram shows the forces acting on the two side arms of the coil.
2) These forces are just the usual forces which act on any current in a magnetic field.
3) Because the coil is on a spindle and the forces act one up and one down, it rotates.
4) The split-ring commutator is a clever way of swapping 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.

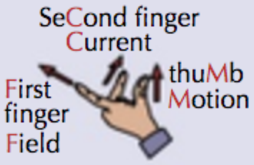
Example: Is this coil turning clockwise or anticlockwise?

Answer:

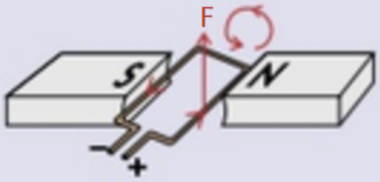
1) Draw in current arrows (+ve to –ve).



2) Use Fleming's LHR on one arm of the coil (I've used the right side).



3) Draw in the direction of force (motion).



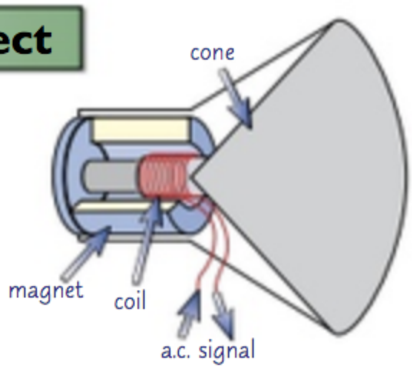
It is turning anticlockwise.

Loudspeakers Work Because of the **Motor Effect**

1) The 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.



The motor effect has a lot of important applications...

For example, food mixers, DVD players and electric drills all use electric motors to keep things turning.

Warm-Up & Exam Questions

It's time for another page of questions to check your knowledge. If you can do the warm-up questions without breaking into a sweat, then see how you get on with the exam questions.

Warm-Up Questions

1) Draw a diagram to show the magnetic field around a single bar magnet.
2) True or false? The further a magnet and a magnetic material are from each other, the stronger the induced magnetism will be.
3) Iron is a soft magnetic material. What does this mean?
4) If you are using Fleming's left-hand rule, in which direction should your second finger point?

Exam Questions

1 A student arranges two magnets as shown below. Grade 4-6

(a) Describe the magnetic field in the shaded region between the dotted lines.

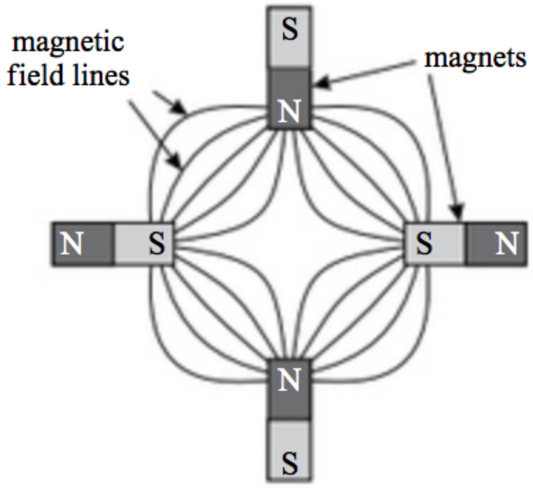
[1 mark]

(b) State whether there will be a force of attraction, repulsion, or no force between the two magnets. Explain your answer.

[2 marks]

PRACTICAL

2 A student draws the magnetic field lines between four bar magnets, as shown in the diagram. Grade 6-7



Describe an experiment that the student could have done to show this magnetic field pattern.

[2 marks]

Exam Questions

PAPER 2

3 An electromagnet is used by a crane to lift, move and drop iron and steel.

(a) The electromagnet contains a solenoid. State what is meant by a **solenoid**.

[1 mark]

(b) Describe the shape of the magnetic field that a solenoid produces.
You may use a sketch to help with your answer.

[2 marks]

(c) When a current is passed through the electromagnet, an iron bar on the ground nearby is attracted to it. When the current is stopped, the bar drops back to the ground. Explain why this happens.

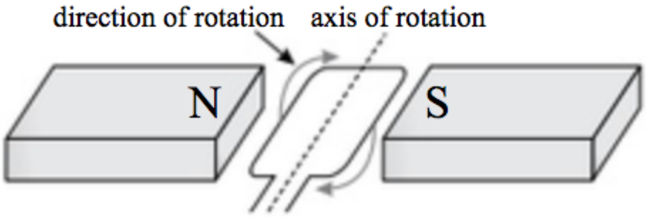
[4 marks]

(d) The crane's electromagnet contains a magnetically soft iron core.

Explain why putting a magnetically hard core in the electromagnet would cause the crane to not work properly.

[2 marks]

4 A student is building a simple d.c. motor. He starts by putting a loop of current-carrying wire into a magnetic field. The wire loop is free to rotate about an axis, as shown in the diagram.



(a) Copy the diagram and add an arrow to show the direction of the current in the wire.

[1 mark]

(b) The starting position of the loop is shown in the diagram. Explain why the motor will stop rotating in the same direction after 90° of rotation from its start position.

[1 mark]

(c) Suggest and explain how the student could get the motor to keep rotating in the same direction.

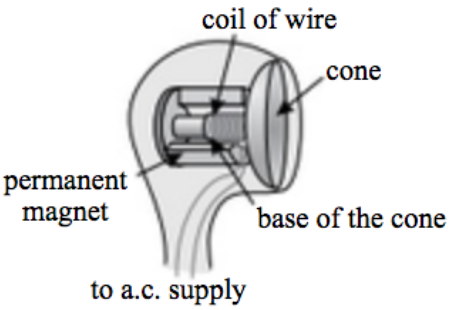
[2 marks]

(d) Give **one** way the motor could be made to rotate faster.

[1 mark]

5 The diagram on the right shows the parts inside an earphone. Sound waves are caused by mechanical vibrations. Explain how the earphone uses an a.c. supply to produce sound waves.

[4 marks]



Electromagnetic Induction

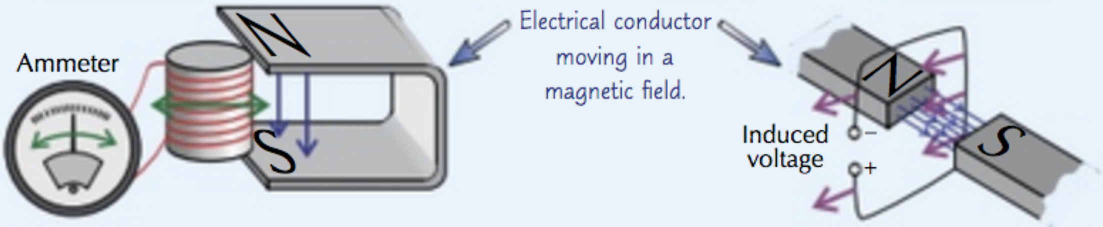
Generators use a pretty cool piece of physics to make electricity from the movement of a turbine.
It's called electromagnetic (EM) induction — which basically means making electricity using a magnet.

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:

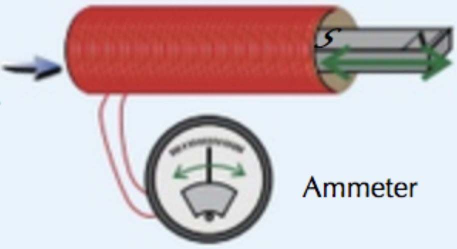
a) An electrical conductor (a coil of wire is often used) moves through a magnetic field.



Electrical conductor moving in a magnetic field.

b) The magnetic field through an electrical conductor changes (gets bigger or smaller or reverses).

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. A generator works the opposite way round — you've got a magnetic field and movement, which induces a current.

Electromagnetic induction transfers energy from kinetic energy stores...

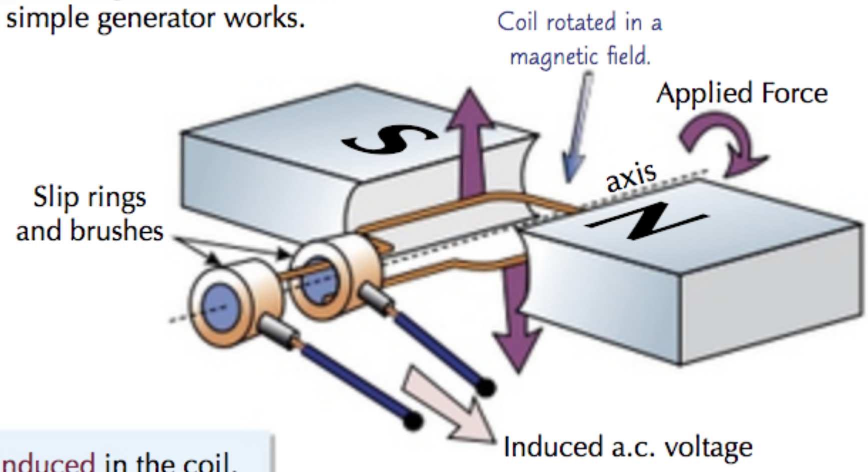
...to electrical energy stores. In a power station, a turbine moves — electromagnetic induction is then used to transfer energy from the kinetic energy store of the turbine to electrical energy stores.

Electromagnetic Induction

Power stations use a.c. generators to produce electricity — it's just a matter of turning a coil in a magnetic field.

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

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



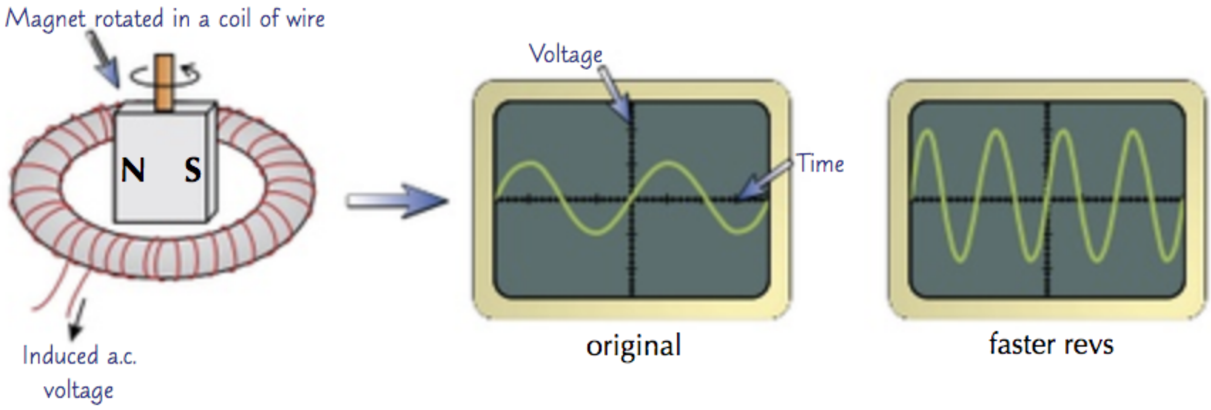
1) Generators rotate a coil in a magnetic field (or a magnet in a coil).

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.

EM induction works whether the coil or the field is moving

EM induction's not as tough as it might look: when you have a conductor, a magnetic field and some movement, you get a voltage (and a current if there's a circuit). So you have no excuse not to learn it.

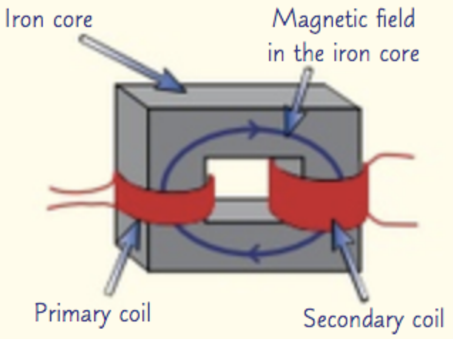
Transformers

Transformers only work with an alternating current. Try using a d.c. battery and you'll be there for days.

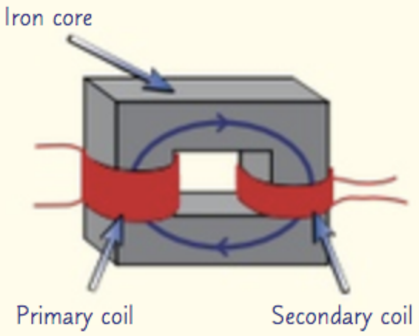
Transformers Change the Voltage (but only Alternating Voltages)

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.
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.

REVISION TIP

Step-up transformers increase the voltage...

If you're struggling to remember the difference between step-up and step-down transformers, try to think about what's changing from the primary coil (input) to the secondary coil (output). If the number of turns is increasing, the voltage will also increase across the transformer — both things have been "stepped up" (increased), so it's a step-up transformer.

Transformers

Transformers are needed to change the voltage of electricity produced in power stations, before it can be transported through the National Grid to be used at home or in factories.

Transformers are Nearly **100% Efficient**, so **Power In = Power Out**

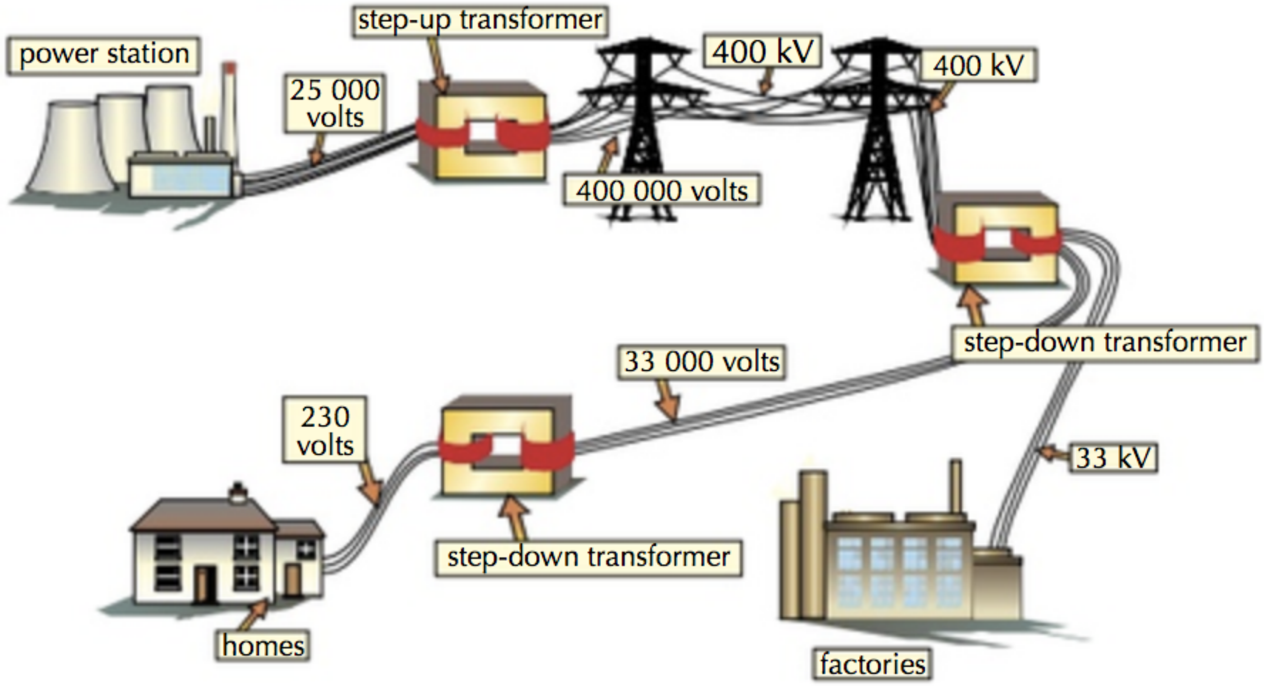
The formula for power supplied is: Power = Voltage × Current or: $P = V \times I$.

So you can rewrite input power = output power as:

$$\overset{\text{primary voltage}}{V_p}\,\overset{\text{primary current}}{I_p} = \overset{\text{secondary voltage}}{V_s}\,\overset{\text{secondary current}}{I_s}$$

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 = $V \times I$, 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.

The national grid — it's a powerful thing...

Electricity is transmitted across the national grid at a low current to reduce energy losses by heating. In order to transmit the power at a low current, a high voltage must be used. To get high voltage and low current, a step-up transformer is used to transfer the electricity from the power station to the national grid.

Warm-Up & Exam Questions

There were lots of new ideas in that section, not to mention the transformer equation. Better have a go at these questions so you can tell what's gone in and what you might need to go over again.

Warm-Up Questions

1) What is electromagnetic induction?
2) True or false? An a.c. generator uses a split-ring commutator.
3) How does a step-up transformer differ from a step-down transformer?

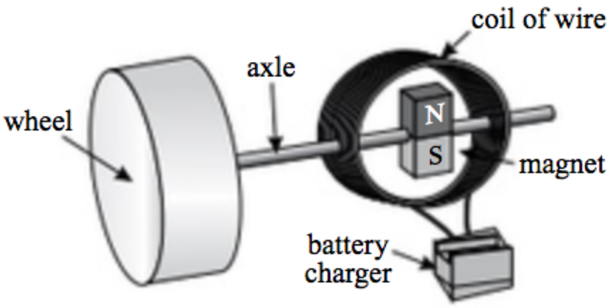
Exam Questions

1 Which of these is **not** an example of electromagnetic induction? Grade 3-4

☐ **A** A coil turned in a magnetic field generates a current in the coil.
☐ **B** A magnet moved in and out of a solenoid creates a voltage in the solenoid.
☐ **C** A current-carrying wire placed between two magnets experiences a force.
☐ **D** A rotating bicycle wheel generates electricity by turning a magnet in a coil.

[1 mark]

2 A student uses the rotation of a hamster wheel to power a battery charger. Grade 6-7



(a) Explain how rotating the wheel creates a voltage across the battery charger.

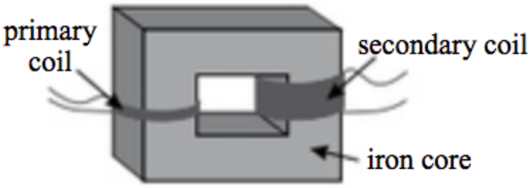
[2 marks]

(b) Give **two** ways the voltage created across the battery charger could be increased.

[2 marks]

PAPER 2

3 The National Grid is a network that transmits electricity around the country. The diagram shows a step-up transformer used in the National Grid. The secondary coil has 16 times more turns on it than the primary coil. Grade 7-9



(a) Explain how transformers are used in the National Grid to transmit electricity from power stations efficiently and supply the electricity to the consumer safely.

[3 marks]

(b) (i) State the equation linking the number of turns on the primary and secondary coils of a transformer and the voltages across the primary and secondary coils.

[1 mark]

(ii) The voltage across the primary coil is 25 000 V. Calculate the voltage across the secondary coil.

[4 marks]

Revision Questions for Section 6

That wraps up Section 6 — take a deep breath and then motor on through these revision questions.

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

Magnets and Magnetic Fields (p.115) ☑

1) What is a magnetic field? ☑
2) Sketch a diagram showing how you can produce a uniform magnetic field using two bar magnets. ☑
3) What happens when a magnetic material is brought into the magnetic field of a magnet? ☑

Electromagnetism, Motors and Loudspeakers (p.116-118) ☑

4) Sketch the magnetic field produced by:
   a) A straight wire. b) A flat loop of wire. ☑
5) What is an electromagnet? ☑
6) Give 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. ☑

Electromagnetic Induction (p.121-122) ☑

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.123-124) ☑

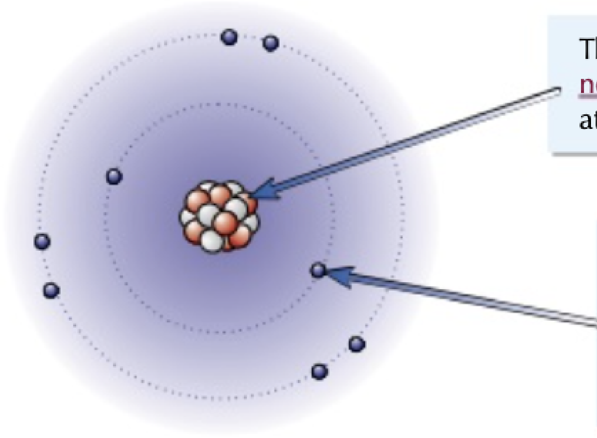
15) What kind of transformer has more turns on the primary coil than the secondary coil? ☑
16) Sketch a diagram of a step-up transformer. ☑
17) Explain how a transformer changes the voltage of an electricity supply. ☑
18) *A transformer has 10 turns on the primary coil and 50 turns on the secondary coil. If the primary voltage is 30 V, what will the secondary voltage be? ☑
19) *The power output of a transformer is 6000 W. If the input voltage is 30 000 V, what is the input current? ☑

*Answers on page 213.

Atoms and Isotopes

Before you get stuck into nuclear radiation, you need to know a bit about atoms and isotopes.

At the Centre of Every Atom is a Nucleus



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.

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).

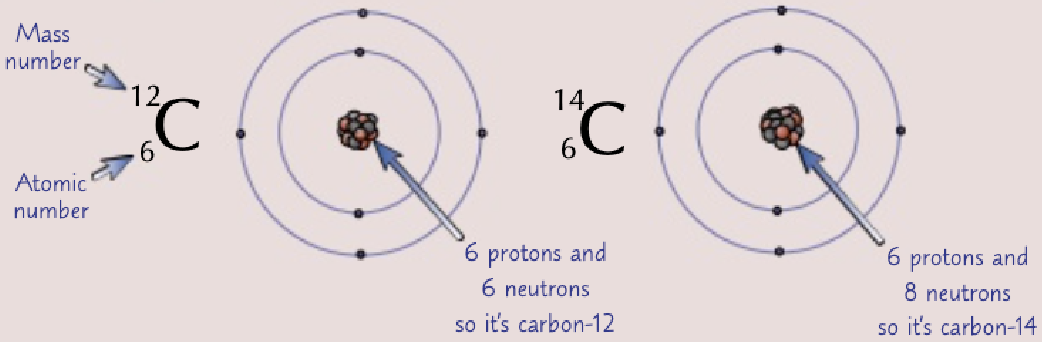
1) The number of protons in the nucleus is called the atomic number, or proton number.
2) Atoms are neutral, so the number of protons = the number of electrons.
3) The total number of protons and neutrons in the nucleus is called the mass number, or nucleon number.

Protons and electrons have an equal but opposite charge.

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).

For example, there are two common isotopes of carbon.
Carbon-14 has two more neutrons than 'normal' carbon (carbon-12).



2) 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.

You can get different isotopes of the same element

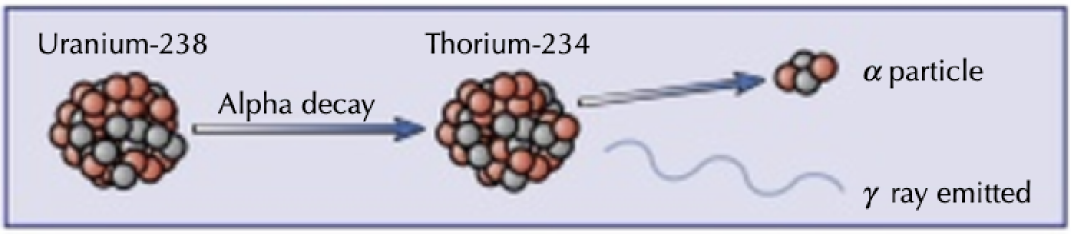
This isotope business can be confusing at first, but remember... it's the number of protons which decides what element it is, then the number of neutrons decides what isotope of that element it is.

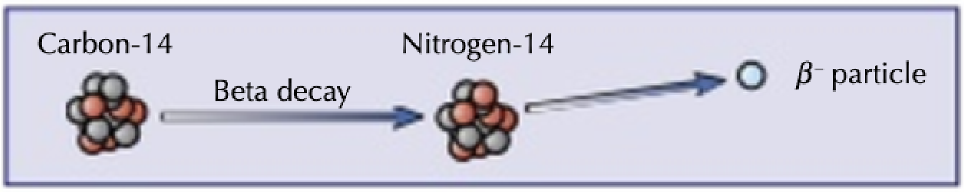
Radioactivity

The nuclei of unstable isotopes can decay and emit radiation. Although you can't see it, nuclear radiation is all around us all the time. And that's what this page is all about.

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) (see next page) or neutrons (n) (see page 130).
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).

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 page 131) or photographic film.

There's more about ionising radiation coming up on the next page.

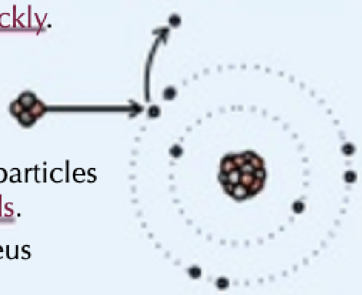
Alpha, Beta and Gamma Radiation

Alpha, beta and gamma are three types of ionising radiation. You need to remember what they are, how well they penetrate materials, and their ionising power.

Alpha Particles are Helium Nuclei

$^{4}_{2}\text{He}$

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 next page for more).

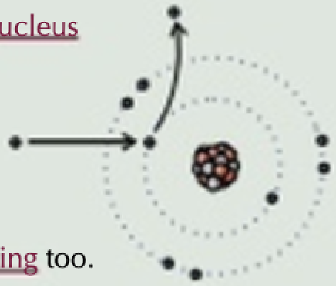


Beta Particles are Electrons

$^{0}_{-1}\text{e}^{-}$

There's more on penetrating power on the next page.

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 (see next page for more).
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

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 page 55).
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 alpha or beta decay. You never get just gamma rays.
6) Gamma ray emission has no effect on the atomic or mass numbers of the isotope (see next page for more). If a nucleus has excess energy, it loses this energy by emitting a gamma ray.

Alpha particles are more ionising than beta particles...

... and beta particles are more ionising than gamma rays. Make sure you've got that clearly memorised, as well as what makes up each type of radiation, since this isn't the last you'll see of this stuff...

Radioactivity and Nuclear Equations

Some stuff on nuclear equations (well it is Physics — there was bound to be an equation somewhere...), and then back to how well the three types of ionising radiation penetrate materials (including air).

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 must 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

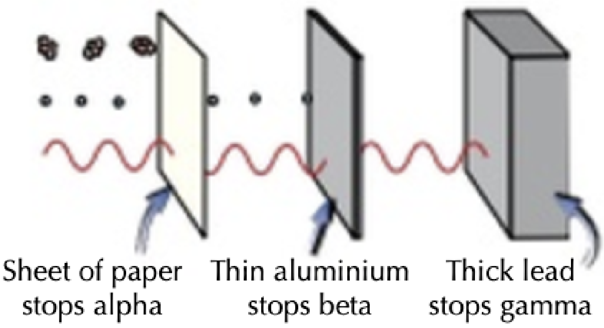
$$^{13}_{4}\text{Be} \longrightarrow {}^{12}_{4}\text{Be} + {}^{1}_{0}\text{n}$$

atomic number stays the same

Neutron radiation is a type of radiation where neutrons are emitted. It's ionising too, but you don't need to know its properties — only how to balance neutron decay equations.

You Can Identify the Type of Radiation 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.



EXAM TIP

Like chemical equations, nuclear equations should be balanced

If you're completing a nuclear equation in an exam, do a quick check when you've finished. Make sure the totals of the atomic numbers and mass numbers of everything on the right are the same as the atomic number and mass number of the thing on the left. If they aren't, something's wrong.

Investigating Radioactivity

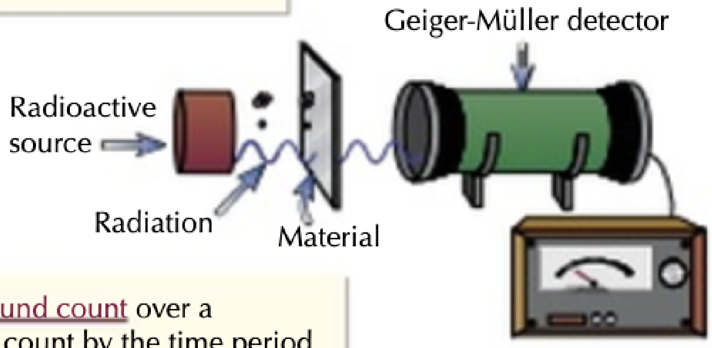
PRACTICAL

You can see for yourself how penetrating the different kinds of radiation are by carrying out the following experiment. It's super-important to be aware of the safety precautions first though.

You can **Investigate** the **Penetration** of Radiation

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 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.

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.

Radioactive Sources Can Be **Dangerous**

Radioactive sources can be dangerous if you don't use them properly (see page 138).

- 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.

PRACTICAL TIP

Always handle radioactive sources safely

OK, so it might be incredibly obvious, but radiation can be so harmful that it's worth saying: if you're doing an experiment that involves using a radioactive source, make sure that you know all of the safety measures that you should be taking — and then make sure that you take them.

Warm-Up & Exam Questions

Well, it's time to test what you know. If you've learnt everything on the previous few pages, you should be able to answer every single one of these questions. Better get started...

Warm-Up Questions

1) What is the nucleon number of a nucleus?
2) What is the name of an atom that has been ionised?
3) Explain why alpha radiation is so strongly ionising.
4) Name the type of nuclear radiation whose particles are electrons.
5) Name the type of nuclear radiation that is a type of electromagnetic wave.

Exam Questions

1 Iodine-131 ($^{131}_{53}\mathrm{I}$) is an unstable isotope of iodine.

(a) (i) Copy and complete the table for an atom of iodine-131.

Particle	**Charge**	**Number present in an atom of iodine-131**
Proton	positive	
Neutron	zero	
Electron		53

[3 marks]

(ii) Name the particle(s) found in the nucleus of an atom.

[1 mark]

(b) What is meant by the term **isotopes**?

☐ **A** atoms with the same atomic number but a different mass number

☐ **B** atoms with the same mass number but a different atomic number

☐ **C** atoms with the same proton number but a different atomic number

☐ **D** atoms with the same number of neutrons but a different number of electrons

[1 mark]

(c) Iodine-131 is a waste product of some power plants and it contributes to the low level of radiation that is present around us all the time.

(i) Give the name of this low level of radiation.

[1 mark]

(ii) Give **two** natural sources of this low level of radiation.

[2 marks]

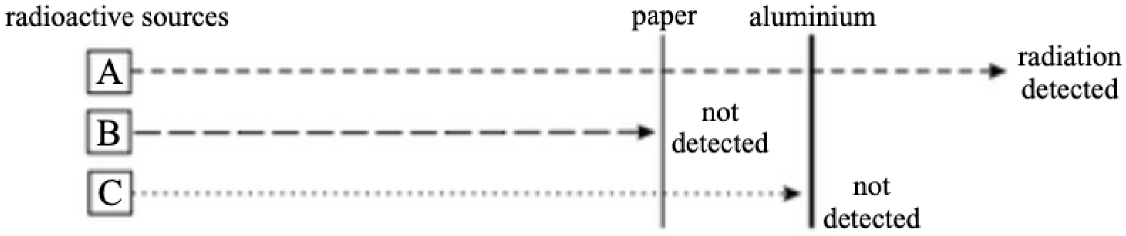
(d) Name **four** types of radiation that can be given out when unstable nuclei decay.

[4 marks]

Exam Questions

PRACTICAL

2 A student is doing an investigation to identify the radiation produced by three unknown radioactive sources. The sources were used to pass radiation through thin sheets of paper and aluminium. A detector was used to measure if radiation had passed through the sheets. The results are shown below.



(a) Suggest the type of radiation that source C produces. Explain your answer.

[2 marks]

(b) The student uses a Geiger-Müller counter to detect the radiation.
Name **one** other detector that can be used to detect radiation.

[1 mark]

(c) Explain why the student subtracts the background radiation count from all the readings shown on the detector before she analyses her results.

[2 marks]

3 Nuclear equations show what is produced when unstable nuclei decay.

(a) Copy and complete the symbol for neutron radiation: $^{\cdots\cdots}_{\cdots\cdots}\text{n}$

[1 mark]

(b) Copy and complete this nuclear equation, which shows a polonium isotope decaying by alpha and gamma emission.

An alpha particle can be written as He or α.

$$^{\cdots\cdots}_{\cdots\cdots}\text{Po} \longrightarrow {}^{195}_{82}\text{Pb} + {}^{\cdots\cdots}_{\cdots\cdots}\alpha + {}^{\cdots\cdots}_{\cdots\cdots}\gamma$$

[4 marks]

4 The unstable isotope lead-212 ($^{212}_{82}\text{Pb}$) decays by emitting nuclear radiation. After the three stages of decay described below, it becomes a different isotope of lead.

1. Lead-212 decays by beta decay to become an isotope of bismuth.
2. The bismuth isotope decays by alpha and gamma decay to become an isotope of thallium.
3. The thallium isotope decays by beta decay into a different isotope of lead.

(a) Describe what happens to the atomic number and the mass number of a nucleus when it undergoes gamma decay.

[2 marks]

(b) State the mass number of the lead isotope that is reached in stage 3. Explain your answer.

[4 marks]

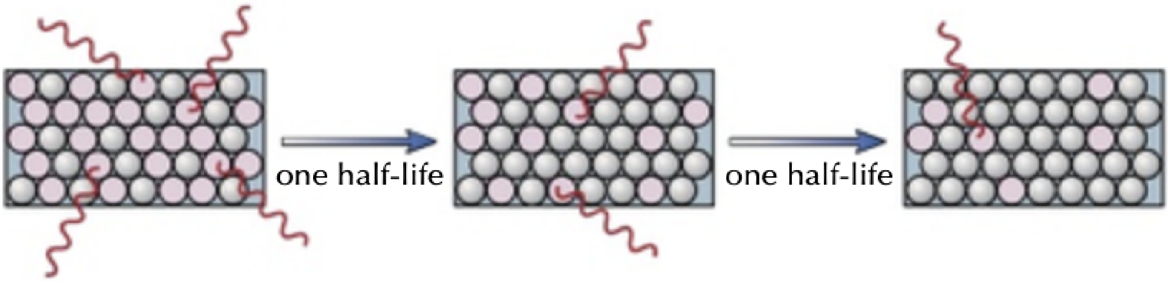
Half-Life

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.

Make sure you've learnt a definition of half-life

Isotopes can have very different half-lives. For example, uranium-235 (used in nuclear power stations) has a half-life of 700 million years, while the half-life of fluorine-18 (used in hospitals) is less than 2 hours.

Half-Life

This page is about how to tackle the two main types of half-life questions.

Do **Half-Life** Questions **Step by Step**

Half-life is maybe a little confusing, but the calculations are straightforward so long as you do them carefully, step by step. Like this one:

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.

Answer: To answer, go through it in short simple steps like this:

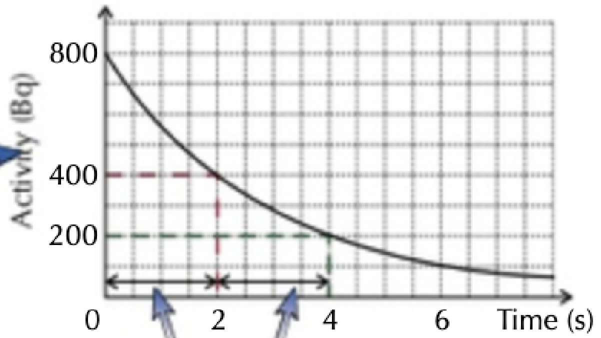
INITIAL count:		after ONE half-life:		after TWO half-lives:		after THREE half-lives:		after FOUR half-lives:
640	(÷2)→	320	(÷2)→	160	(÷2)→	80	(÷2)→	40

It takes four half-lives for the activity to fall from 640 to 40.
This means that two hours represents four half-lives, so the half-life is (2 hours ÷ 4) = 30 minutes.

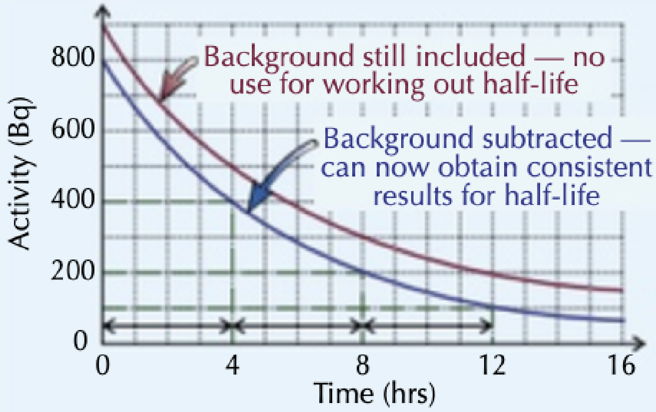
Measuring the **Half-Life** of a Sample Using a Graph

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.



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. 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.

MATHS TIP

Show your working on the graph

Don't just estimate the time at which the activity reaches a certain value — get out your ruler and draw some lines between the axes and the graph line to find it accurately. This will also show the examiner that you know what you're doing and have followed the correct method.

Uses of Nuclear Radiation

Nuclear radiation can be really useful — but you've got to be careful about what isotope you use.

Medical Tracers Use Beta or Gamma Radiation

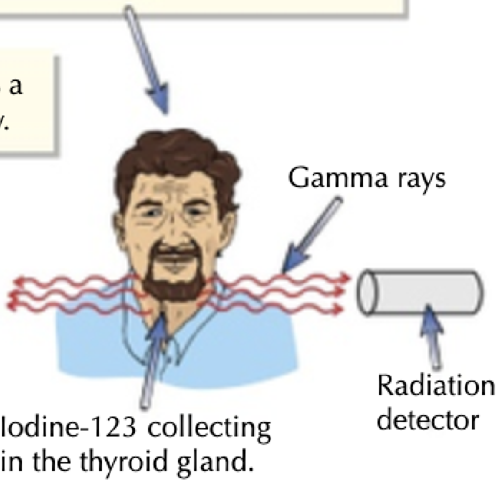
Beta and gamma will penetrate the skin and other body tissues.
This makes them suitable as medical tracers:

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.

2) As the source moves around the body, the radiographer uses a detector and a computer to monitor its progress on a display.

3) Doctors use this method to check whether the organs of the body are working as they should.

4) 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.



5) 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 138).

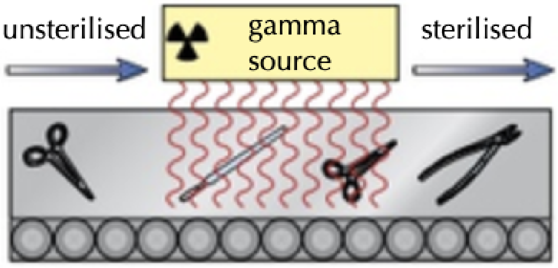
Food and Equipment can be Sterilised Using Gamma Rays

1) Food can be irradiated (see page 138) with 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 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.



More Uses of Nuclear Radiation

Yep, there are even more ways in which nuclear radiation has proved itself useful. Take a look...

Radiation is Also Used to **Treat Cancer**

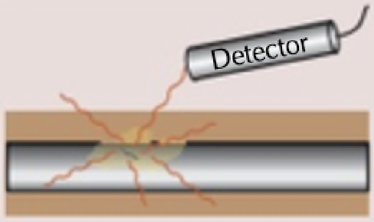
1) You'll see on the next page that ionising radiation can kill or damage cells and tissues — and this can cause cancer. But once the cancer's started, ionising radiation can also be used to treat it.

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.

Radiation is Used in Industry for **Tracers** and **Thickness Gauges**

Gamma Radiation in Industrial Tracers

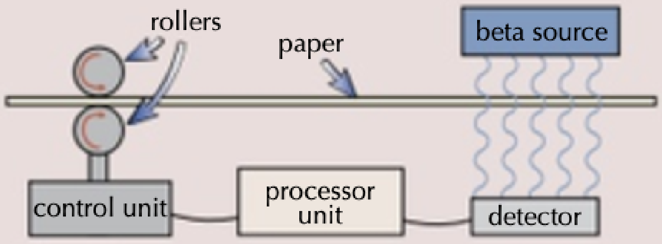
1) Gamma emitting tracers are used in industry to detect leaks in underground pipes.
2) The source is allowed to flow down the pipe and a detector is used above ground. Gamma is used because it can pass through any rocks or earth surrounding the pipe.
3) If there's a crack in the pipe, more radiation 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.

Beta Radiation in Thickness Gauges

1) Beta radiation is used in thickness control.
2) 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.



3) It needs to be a beta source, because then the paper will partly block the radiation (see page 130). 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

To make use of radiation, you've got to match the requirements of the job to your source's properties. If the radiation needs to go through any kind of material, then an alpha source won't be any good to you.

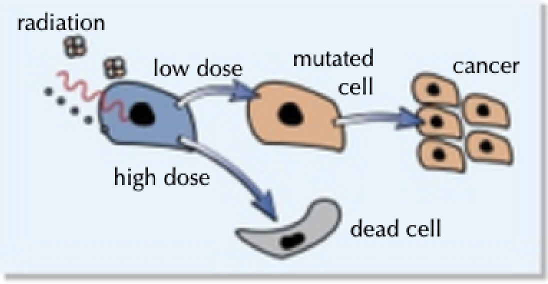
Risks from Nuclear Radiation

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**

The properties of alpha, beta and gamma are on page 129.

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.



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.
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) — e.g. 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.

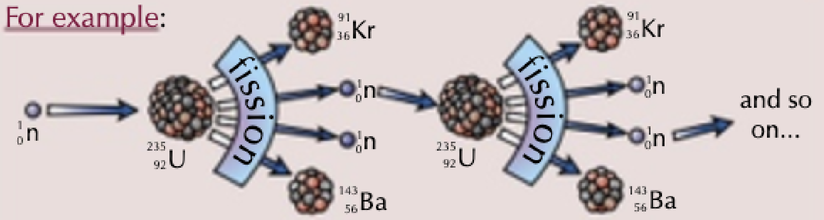
Nuclear Fission

Most power stations get the energy they need to drive the generators by burning fuel (e.g. coal) or from the natural motion of something (e.g. waves, tides). Nuclear power stations do it a bit differently...

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.

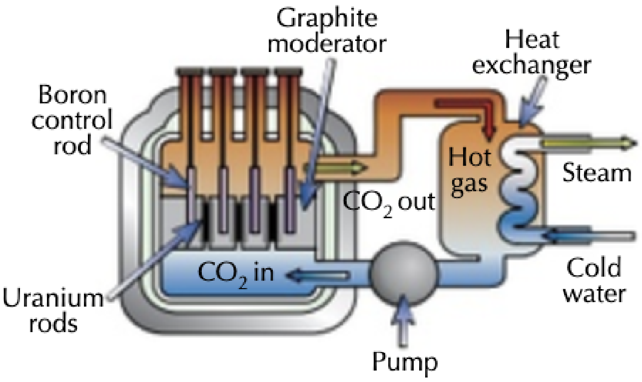
For example:



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 power releases a lot of energy, but it has its downsides

Nothing to it really: throw in some neutrons, split some atoms, get some heat, make some steam, turn a turbine, drive a generator and there you have it — some electricity. But the big problem is how to dispose of the waste — the products left over are generally radioactive, so they can't just be thrown away.

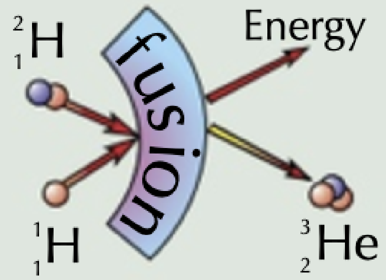
Nuclear Fusion

Nuclei can be joined together, as well as split apart. But power stations can't take advantage of this (yet).

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, lighter nuclei did. Some of the mass of the lighter nuclei is converted to energy (don't panic, you don't need to know how) and released.

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.

Fusion Only Happens at **High Temperatures** and **Pressures**

1) 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 (see page 45).

2) 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.

Why do we even bother?

Building a working fusion reactor is a real headache. It's expensive, difficult and no one's got it quite right yet. So what's the point? Well, it releases loads of energy. And the main waste produce is helium, which is neither radioactive nor a greenhouse gas. So some people believe it could solve the current energy crisis.

Warm-Up & Exam Questions

Here we go again — time to test your knowledge with some specially selected questions.
The warm-up questions should ease you in. Try them out before you dive into the exam questions.

Warm-Up Questions

1) What units is radioactivity measured in?
2) Name the two types of radiation that can be used in medical tracers.
3) How could you use gamma rays to detect a leak in an underground pipe?
4) Why is it important that sites where high-level radioactive waste is buried are geologically stable?

Exam Questions

1 A sample of a radioactive isotope has a half-life of 40 seconds.

(a) (i) The initial activity of the sample is 8000 Bq. Calculate the activity after 2 minutes.

[2 marks]

(ii) Calculate the number of whole minutes it would take for the activity to fall below 200 Bq from its initial activity.

[3 marks]

(b) Which of the following statements about half-life are true?

1. Two samples of the same size but of different isotopes would have the same half-life.
2. Two samples of the same size but of different isotopes would have different half-lives.
3. Two samples of the same isotope of different sizes would have the same half-life.
4. Two samples of the same isotope of different sizes would have different half-lives.

☐ **A** 2 and 3 only

☐ **B** 4 only

☐ **C** 2 and 4 only

☐ **D** None of the statements

[1 mark]

2 A scientist is concerned about contamination and irradiation in her lab.

(a) State what is meant by **contamination**.

[1 mark]

(b) The scientist is using a low activity radioactive sample.
Give **one** example of how she can protect herself from irradiation
and **one** example of how she can protect herself from contamination.

[2 marks]

Exam Questions

3 Iodine-123 is a gamma emitter commonly used as a tracer in medicine.

(a) Describe how iodine-123 can be used to detect whether the thyroid gland is absorbing iodine as it normally should do.

[2 marks]

(b) Explain why alpha emitters cannot be used as tracers in medicine.

[4 marks]

(c) This table shows the properties of three other radioisotopes.

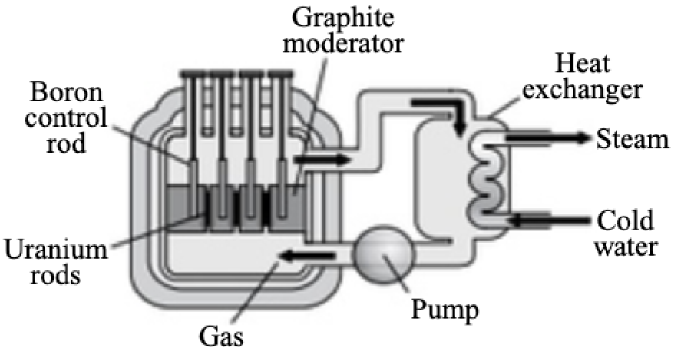
State which of these would be best to use as a medical tracer.

Explain your answer.

Radioisotope	Half-life	Type of emission
technetium-99m	6 hours	gamma
phosphorus-32	14 days	beta
cobalt-60	5 years	beta/gamma

[2 marks]

4 Nuclear fission takes place in nuclear reactors. The diagram shows the basic structure of a gas-cooled nuclear reactor.



(a) Give **one** fuel that can be used in a nuclear reactor.

[1 mark]

(b) (i) Describe what happens during a single nuclear fission event and state the products formed.

[4 marks]

(ii) Explain how nuclear fission can be used to produce energy continuously in a nuclear reactor, and how part of the nuclear reactor is designed to help this happen.

[3 marks]

(c) Explain the purpose of the control rods in a nuclear reactor.

[1 mark]

5 Two protons are fired at each other and combine to form a hydrogen-2 nucleus. Describe the conditions required for this reaction to occur and explain why they are needed.

[3 marks]

Revision Questions for Section 7

That's Section 7 over and done with — time to find out how much of it you can remember.

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

Isotopes and Nuclear Radiation (p.127-131) ☑

1) What is the atomic number of a nucleus? ☑
2) What is the mass number of a nucleus? ☑
3) What are atoms with the same number of protons but different numbers of neutrons called? ☑
4) Briefly describe what background radiation is and where it comes from. ☑
5) Describe what alpha, beta and gamma radiation are. ☑
6) Which is the most ionising out of alpha, beta and gamma radiation? ☑
7) Which is the most penetrating 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) What quantities need to be the same on each side of a nuclear equation? ☑

Half-Life (p.134-135) ☑

13) What is meant by the 'activity' of a radioactive source? ☑
14) Define half-life. ☑
15) 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.136-138) ☑

16) Briefly describe two uses of nuclear radiation in medicine. ☑
17) Explain why alpha radiation could not be used to check the thickness of metal sheets. ☑
18) Other than thickness gauges, give one other use of nuclear radiation in industry. ☑
19) Why is nuclear radiation dangerous to living organisms? ☑
20) Explain why radioactive waste is difficult to dispose of safely. ☑

Fission and Fusion (p.139-140) ☑

21) What are the products of the nuclear fission of uranium-235? ☑
22) True or false? The fission products of uranium-235 are also radioactive. ☑
23) What job does shielding do in a nuclear reactor? ☑
24) What is the name of the process in which two light nuclei collide at high speed and join together? ☑

The Universe

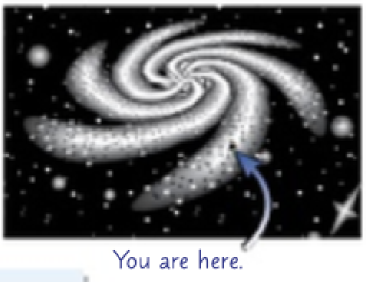
There's all sorts of exciting stuff in the universe... Our whole solar system is just part of a huge galaxy. And there are billions upon billions of galaxies. Which should tell you that the universe is pretty big...

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.



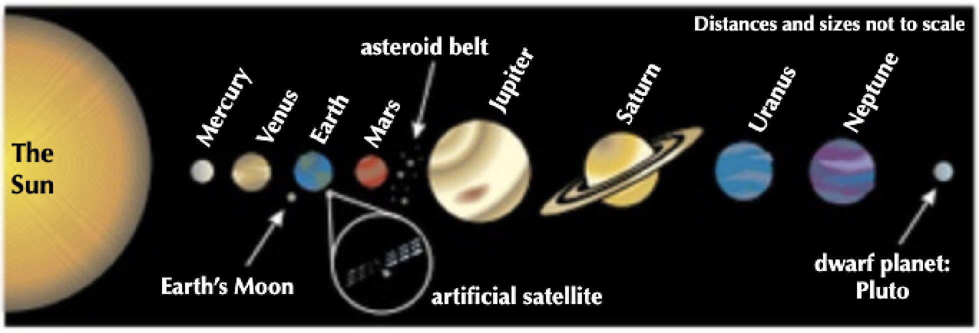
4) The distance between neighbouring stars in the galaxy is often millions of times greater than the distance between planets in our solar system.

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.

Our Solar System has **One** Star — The **Sun**



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 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.

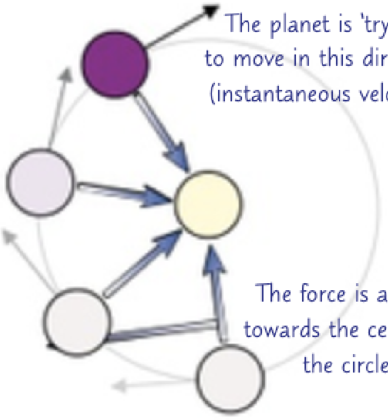
A satellite is an object that orbits a second, more massive object.

Gravity and Orbits

The structure of the Solar System is determined by orbits — the paths that objects take as they move around each other in space. I bet you can't wait to find out more. Well, read on...

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 next page).

The **Force** due to Gravity Depends on **Mass** and **Distance**

1) Back on page 5 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.

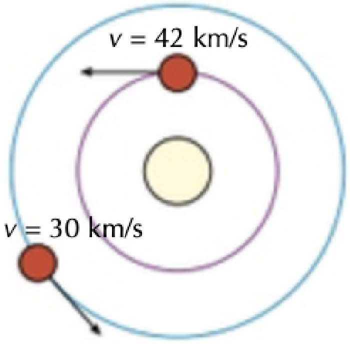
2) Gravitational field strength depends on the mass of the body creating the field. The larger the mass of the body, the stronger its gravitational field. (The Earth is more massive than the Moon, so an object would weigh more on Earth than it would on the Moon.)

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.

Gravity and Orbits

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:

$$\boxed{\textbf{speed} = \frac{\textbf{distance}}{\textbf{time}}}$$

2) For a circular orbit, the distance travelled is the circumference of the orbit, which is given by the formula:
distance = 2 × π × radius of orbit

3) So the formula for the speed of an orbit is:

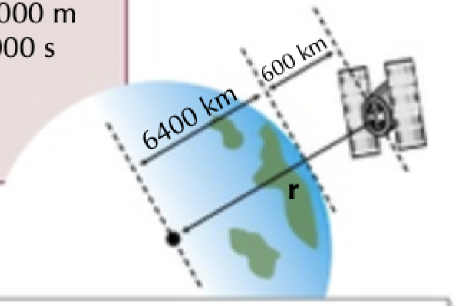
$$\boxed{\textbf{orbital speed} = \frac{\mathbf{2 \times \pi \times} \textbf{orbital radius}}{\textbf{time period}}} \qquad \boxed{v = \frac{2\pi r}{T}}$$

Remember: '*r*' is the distance between the centre of the planet or star and the object that is orbiting around it.

Example: Calculate the speed in m/s of a satellite that is 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 min to orbit the Earth once.

Answer: First calculate r in m: $r = 6400 + 600 = 7000$ km = 7 000 000 m
Then find the time period in seconds, $T = 200 \times 60 = 12\,000$ s

$$\text{So orbital speed} = \frac{2 \times \pi \times 7\,000\,000}{12\,000}$$
$$= 3665.191...\ \text{m/s} = 3700\ \text{m/s (to 2 s.f.)}$$



MATHS TIP

Pay close attention to the units of values you're given...

The values you get given in the question may not be in units you want for the equation, especially when it's large values like orbital radius in the question above. Make sure you convert them first.

Warm-Up & Exam Questions

Astronomy has some pretty cool stuff, but that doesn't mean you can escape a few practice questions...

Warm-Up Questions

1) Name the galaxy where our solar system is located.
2) Give two factors that affect the strength of the gravitational force on an object orbiting a planet.
3) A planet orbits a star at a distance of 55 000 000 km. It takes 1800 hours to orbit the star. Assuming its orbit is circular, find the planet's orbital speed in m/s.

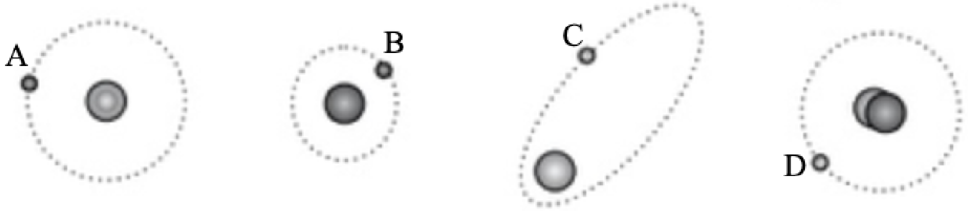
Exam Questions

1 Which of the following correctly describes a galaxy?

☐ **A** a star surrounded by orbiting planets
☐ **B** a collection of billions of stars
☐ **C** a collection of billions of universes
☐ **D** a collection of 5 to 10 stars

[1 mark]

2 The diagrams below represent the orbits of four different objects in space.



(a) Which of the objects, A, B, C or D, is most likely to be a comet? Explain your answer.

[2 marks]

(b) Objects A and D have the same time period and orbital radius. Object D has an orbital speed of 1.2 km/s. What is the orbital speed of object A? Give a reason for your answer.

[1 mark]

(c) Object B has an orbital radius of 42 000 km and a time period of 24 hours. Calculate the orbital speed of object B in m/s.

[3 marks]

3 A comet orbits a star with a varying orbital radius and speed. It completes one orbit in 72.0 years and its orbital speed is 48.1 km/s at the fastest point in its orbit.

(a) Calculate the time period of the comet's orbit in seconds. Assume there are 365 days in a year.

[1 mark]

(b) At which point in the comet's orbit will its speed be greatest? Explain your answer.

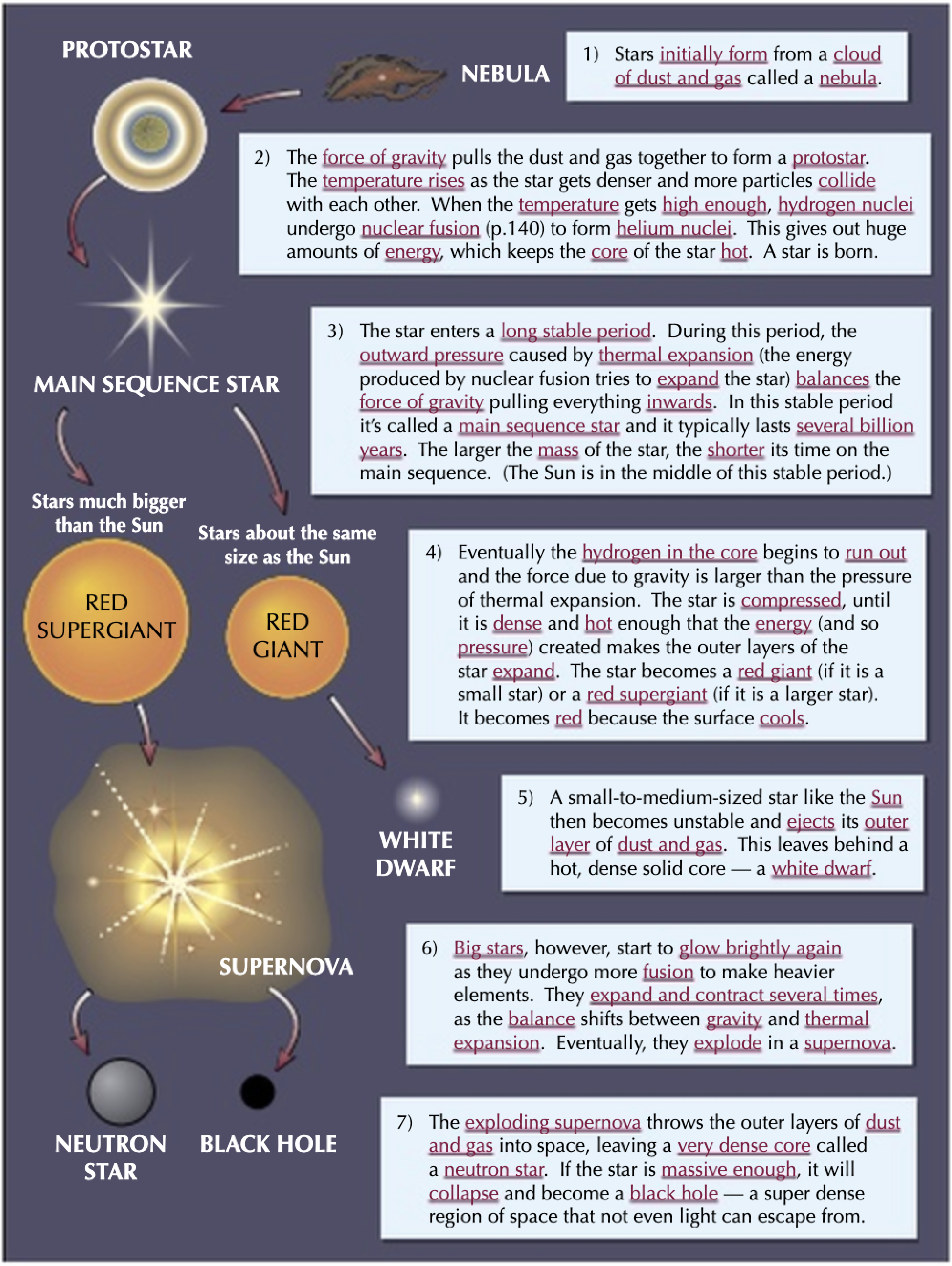
[2 marks]

(c) A planet travels in a circular orbit around the same star. It has the same orbital period as the comet and a constant orbital speed of 7.4 km/s. Calculate the orbital radius of this planet in metres.

[3 marks]

Stellar Evolution

Stars go through some dramatic transformations during their life cycle.



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.140) 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 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 larger the mass of 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 region of space that not even light can escape from.

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 light of each frequency a star emits will depend 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 55), 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 light (red and orange), and so they appear blue.

Paper 2

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.

Paper 2

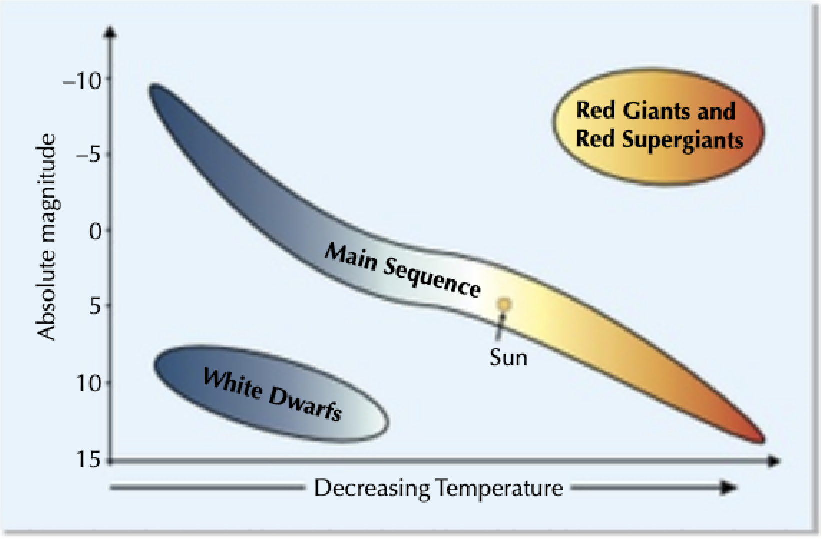
Bigger and hotter stars are brighter than smaller and cooler ones...

Blue stars are brighter than red stars of the same size because they're hotter, but many red stars are brighter than hotter stars because they are much bigger — e.g. red giants are much brighter than white dwarfs.

Classifying Stars and Red-Shift

The **Hertzsprung-Russell Diagram** Shows Different Types of Star

1) The Hertzsprung-Russell diagram is a graph of absolute magnitude against temperature for 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.

Waves are Affected by the **Motion** of the **Source**

1) As you saw on page 53, when a source of waves is moving relative to the observer, the waves will undergo an 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 the light that reaches us from distant galaxies. This light is red-shifted — we observe light with a longer wavelength (lower frequency) than we would expect these galaxies to emit. The galaxies must be moving away from the Earth.

REVISION TIP

Make sure you can draw a basic Hertzsprung-Russell diagram...

Remember that the axes on a Hertzsprung-Russell diagram are back to front — temperature decreases as you go along the x-axis, and absolute magnitude decreases as you go up the y-axis.

More on Red-Shift

Knowing how much the light from galaxies is red-shifted means you can calculate their velocities.

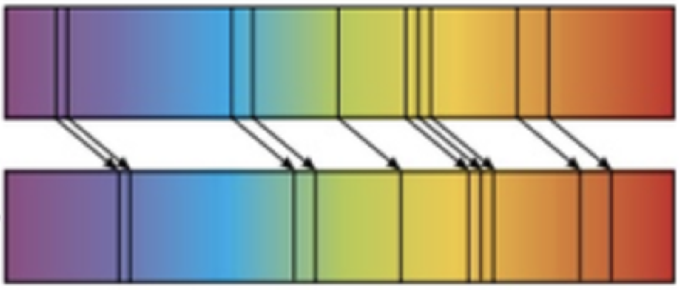
Light from Galaxies is Red-shifted

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.

An absorption spectrum showing dark lines measured on Earth.



The same absorption spectrum measured from light from a distant galaxy. The dark lines in this spectrum are red-shifted.

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 by which 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.

Answer: Rearrange the equation for velocity:

The speed of light is 3.00×10^8 m/s.

$$v = \frac{\lambda - \lambda_0}{\lambda_0} \times c = \frac{(425 \times 10^{-9}) - (410 \times 10^{-9})}{410 \times 10^{-9}} \times 3.00 \times 10^8 = 1.0975... \times 10^7$$

$$= 1.10 \times 10^7 \text{ m/s (to 3 s.f.)}$$

MATHS TIP

You'll find standard form all over the place...

Physics covers everything from tiny particles to giant stars. That means dealing with huge numbers and with tiny numbers. So, unless you want to spend all day writing zeros, you've got to get used to using standard form. After all, writing 3.00×10^8 m/s is easier than writing 300 000 000 m/s.

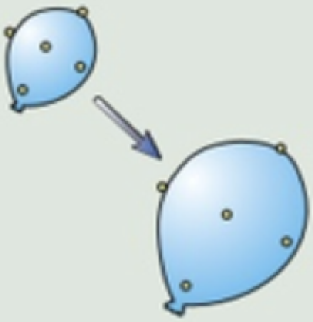
The Big Bang

'How did it all begin?' is a tricky question. The most widely-accepted theory now is the Big Bang theory.

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) 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 radiation from this initial explosion.

We can't say for sure if the Big Bang theory is correct...

...it's just the best theory that we have at the moment — but new evidence might mean it needs adapting.

Warm-Up & Exam Questions

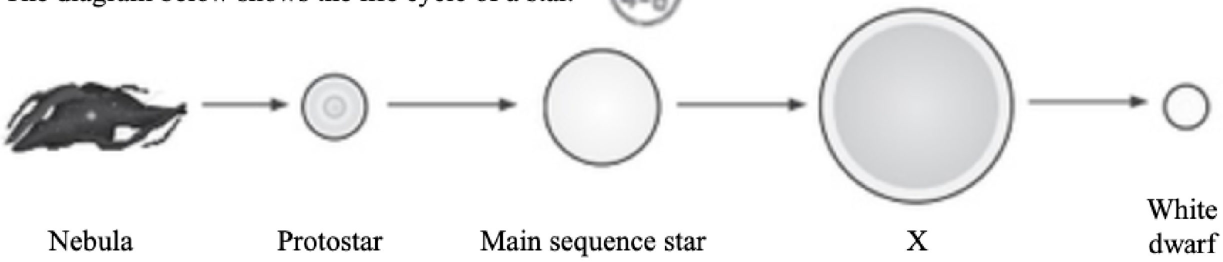
You're so close to the end of the section. Time for just a few more questions before you can take a break, have a brew and give yourself a pat on the back for making it this far.

Warm-Up Questions

1) True or false? The larger the mass of a star, the more time it spends on the main sequence.
2) Explain why very hot stars appear blue.
3) Give one reason why a dim star might look as bright as a very bright star when seen from Earth.
4) What does red-shift suggest about the motion of galaxies?

Exam Questions

1 The diagram below shows the life cycle of a star.



(a) What is the name of the life cycle stage marked X?

☐ **A** red supergiant ☐ **B** red giant ☐ **C** red dwarf ☐ **D** neutron star

[1 mark]

(b) State what is meant by a **nebula**.

[1 mark]

(c) Name the force responsible for 'pulling together' a nebula as it begins to form a star.

[1 mark]

2 The table below shows some properties of a number of stars.

(a) Which of the following shows the stars in the correct order of hottest to coolest?

☐ **A** Megrez, Alkaid, Pollux
☐ **B** Alkaid, Pollux, Megrez
☐ **C** Pollux, Megrez, Alkaid
☐ **D** Alkaid, Megrez, Pollux

[1 mark]

Star	Absolute Magnitude	Colour
Megrez	+1.3	White
Pollux	+1.1	Orange
Alkaid	–0.6	Blue

PAPER 2

(b) State and explain which of the stars in the table is the brightest.

[2 marks]

Exam Questions

PAPER 2

3 The table shows a list of galaxies and their distance from Earth in light years.

Galaxy	Distance From Earth (light years)
Cigar Galaxy	12 million
Black Eye Galaxy	24 million
Sunflower Galaxy	37 million
Tadpole Galaxy	420 million

1 light year ≈ 9.5×10^{15} m

The light from the galaxies in the table shows red-shift.

(a) From which of the galaxies in the table would you expect the light to show the greatest red-shift? Explain your answer.

[3 marks]

(b) Explain how the red-shift of light from distant galaxies provides evidence for the Big Bang model.

[4 marks]

4 Betelgeuse is a star which is much more massive than our Sun.

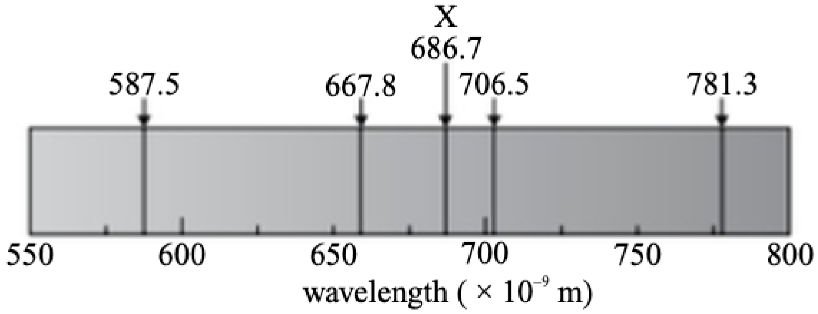
Describe the life cycle of a massive star like Betelgeuse, beginning from a cloud of dust and gas.

[6 marks]

PAPER 2

5 An astronomer is analysing the light received from a distant galaxy, known as Hoag's Object.

To do this, she compares the absorption lines of helium observed in the light from Hoag's Object with the known absorption spectrum of helium on Earth. Part of the known absorption spectrum of helium is shown below.



The astronomer notices that the absorption line for light with a reference wavelength, λ_0, of 587.5×10^{-9} m in the known spectrum appears to correspond to a wavelength of 612.5×10^{-9} m in the light received from Hoag's Object. The speed of light in free space, $c = 3.0 \times 10^8$ m/s.

(a) Calculate the velocity of Hoag's Object.

[3 marks]

(b) Calculate the wavelength at which the absorption line marked X in the spectrum above will appear in the light received from Hoag's Object.

[3 marks]

Revision Questions for Section 8

Stellar job, you've finished Section 8 — now stop gazing at stars and shift your attention to some questions...

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

Galaxies, Our Solar System and Orbits (p.144-146) ☐

1) 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) Write down the formula that you would use to calculate the orbital speed of an object, assuming that its orbit was circular and that you knew its orbital radius and time period. ☐

The Life Cycle of Stars (p.148) ☐

5) What causes the rise in temperature that leads to nuclear fusion in a protostar? ☐
6) What causes a main sequence star to remain stable for a long time? ☐
7) What happens to a star about the same size as our Sun when it's core begins to run out of hydrogen? ☐
8) What is a white dwarf and how is it made? ☐
9) True or false? The Sun will eventually turn into a black hole. ☐

Classification of Stars, Red-shift and the Big Bang (p.148-152) ☐

10) What colour of star has the lowest surface temperature? ☐
11) True or false? The higher the absolute magnitude, the brighter the star. ☐
12) Sketch the Hertzsprung-Russell diagram and label the regions of the graph corresponding to white dwarfs, main sequence stars, red giants and red supergiants. ☐
13) What is red-shift? ☐
14) *A galaxy is moving away from Earth at a velocity of 7.8×10^6 m/s. The light from the galaxy is red-shifted by 15×10^{-9} m when observed from the Earth. Calculate the original wavelength of the light emitted by the galaxy. ☐
15) True or false? Very distant galaxies are moving away faster than ones closer to us. ☐
16) What does CMB stand for? ☐
17) Briefly describe the ideas that make up the Big Bang theory. ☐

*Answer on page 215.