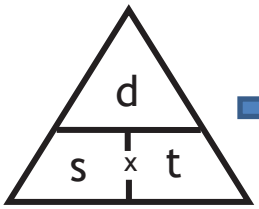
Unit 1 - Motion

Calculating Speed

Speed is defined as the distance moved per unit time, and hence, the equation for speed is :

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

$$s = \frac{d}{t}$$



...and the other two forms of the equation are :

$$d = s \times t$$

$$t = \frac{d}{s}$$

Distance is measured in	**metres (m)**
Time is measured in	**seconds (s)**
Speed is measured in	**metres per seconds (m/s)**

Example 1

If a school bus moves 1600 metres at an average speed of 12.5 m/s, how long did the journey take ?

$$t = \frac{d}{s} = \frac{1600}{12.5} = 128 \text{ s}$$

Look !! Since it's **time** we're calculating, the answer must have units of **seconds.**

Example 2

An electron in orbit around an atom moves at a speed of 2500 km/s !
How far would it travel (in a straight line) if it moved at this speed for 1 minute ?

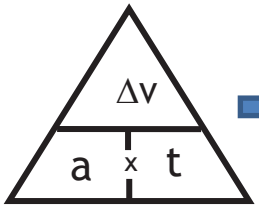
$$d = s \times t = 2\,500\,000 \times 60 = 1.5 \times 10^8 \text{ m}$$ (Almost 4 times around the Earth !)

Look !! It's safer to use all values in metres and seconds (rather than km and minutes).
So, 2500 km/s = 2500 x 1000 = 2 500 000 m/s

Calculating Acceleration

Another equation you'll need is the one for acceleration.
Acceleration is defined as the change in velocity (or speed) per second :

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



...and the other two forms of the equation are :

$$\Delta v = a \times t$$

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

Info. ! *Notice the triangle symbol (Δ) in front of the "v". It's the Greek letter 'delta'. In this case it means 'change in'.*

Change in velocity is measured in	**metres per second (m/s)**
Time is measured in	**seconds (s)**
Acceleration is measured in	**metres per second^2 (m/s^2)**

Example 1

A cyclist increases her speed from 5m/s to 19m/s in 7 seconds.
What is her acceleration?

$$a = \frac{\Delta v}{t} = \frac{(19 - 5)}{7} = \frac{14}{7} = 2 \text{ m/s}^2$$

Example 2

An oil tanker can decelerate at a maximum rate of 0.04 m/s^2. How long will the tanker take to come to a complete stop if initially travelling at a speed of 12 m/s ?

$$t = \frac{\Delta v}{a} = \frac{(12)}{0.04} = 300 \text{ s}$$

(A full 5 minutes !)

Example 3

A football moving forwards at a speed of 12.4 m/s, is kicked forwards so that its speed increases. The acceleration of the ball is 48.0 m/s^2, which lasts for 0.45 s. What's the final speed of the ball after this acceleration ?

Change in speed, $\Delta v = a \times t = 48.0 \times 0.45 = 21.6$ **m/s**

So, final speed $= 12.4 + 21.6 =$ **34.0 m/s**

Motion graphs

The motion of an object can be shown on one of two types of graphs : distance-time or velocity-time graphs (sometimes called speed-time graphs).

Distance - time graphs

There's ONE rule for a d-t graph :

The 'steepness' (or more correctly 'slope' or 'gradient') of this graph indicates the speed of the object.

So,

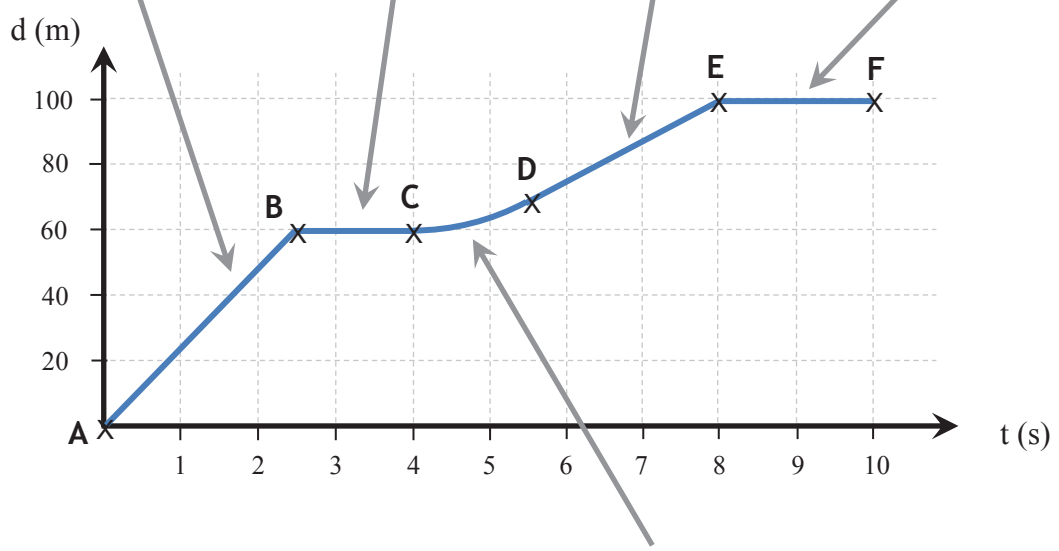
a STEEP line	➔	**a high speed**
a less steep line	➔	**a lower speed**
a flat/horizontal line	➔	**not moving**

In the 1st section, the object is moving an equal distance each second. Hence, the object is moving at a 'constant speed'.

From **B** to **C**, the object is staying at a distance of 60m, so is not moving at all, i.e. **stationary**

This is a straight, diagonal line like section **AB**, and so is moving at a 'constant speed'. However, this is not as steep, so is moving **slower** than **AB**.

EF is again stationary.



This section is more difficult - since the slope is increasing, the speed is increasing, i.e. the object is **accelerating** !

Motion graphs

Velocity - time graphs

(or 'speed-time' graphs)

There are TWO rules for a v-t graph :

1. The slope/gradient is equal to the acceleration.

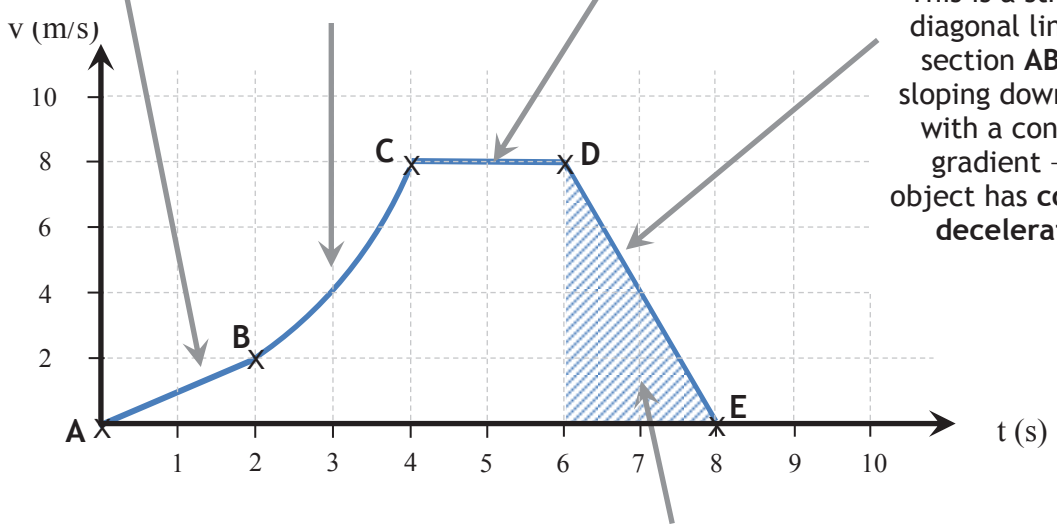
2. The area under the graph is equal to the distance travelled.

In the 1st section, the object is speeding up steadily since the gradient is constant (straight line), i.e. it has **constant acceleration**

Curved line shows non-constant acceleration. Gradient/steepness increasing, so acceleration is increasing.

From **C** to **D**, the gradient is zero, and so, from rule 1 above, the acceleration is zero. This means the object is staying at the same speed (8 m/s), i.e. **constant velocity**

This is a straight, diagonal line like section **AB**, but sloping downwards with a constant gradient - the object has **constant deceleration**



The distance travelled in any section can be calculated from the area below the line, in this case the area of the shaded triangle :

$$\text{Distance} = \text{area} = \frac{\text{base x height}}{2} = \frac{2 \times 8}{2} = \frac{16}{2} = \textbf{8 metres}$$

Calculating the average/mean acceleration in section BC :

$$a = \frac{\Delta v}{t} = \frac{8 - 2}{2} = \frac{6}{2} = 3 \text{ m/s}^2$$

NOTE : Calculating the average speed in a sloping section is easy !! Since only straight line sections are used for this, it's simply half way between the start and end speed for that section e.g. for section DE, the average speed is 4 m/s (half way between 8 m/s and 0 m/s)

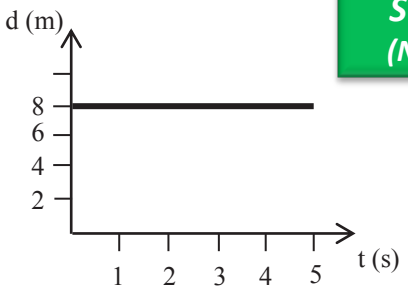
Motion graphs

The motion of an object can be shown on one of two types of graphs : distance-time or velocity-time graphs (sometimes called speed-time graphs).

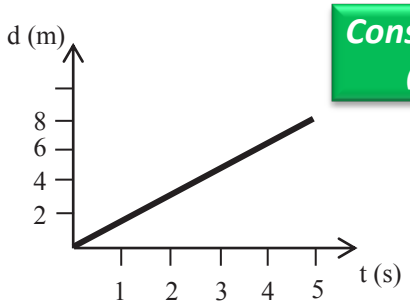
It's important that you learn what the shape of each type of graph tells you about the object's motion :

Distance - time graphs

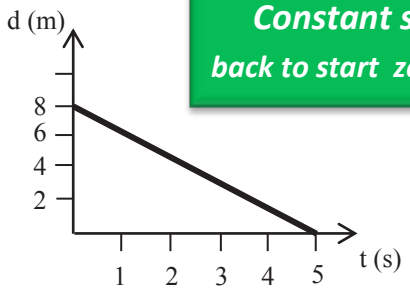
Stationary
(Not moving)



Constant speed
(forwards)

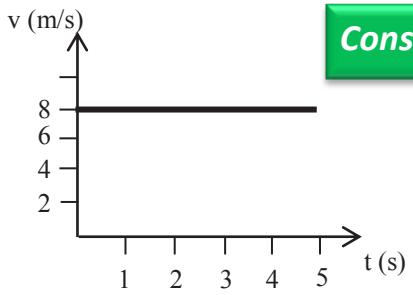


Constant speed –
back to start zero metres)

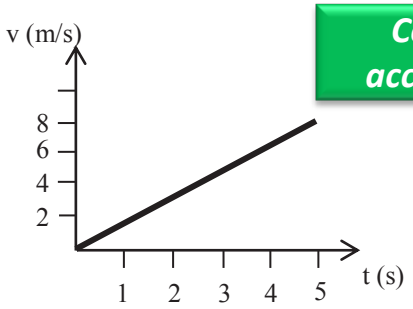


Velocity - time graphs

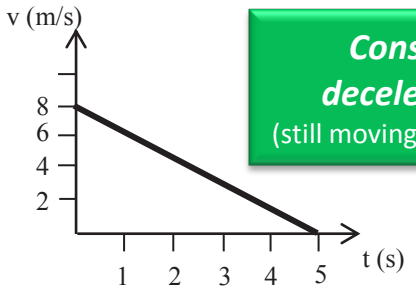
Constant speed



Constant acceleration



Constant deceleration
(still moving forwards !!)



Unit 2 - Forces

Forces

A force is a **push** or a **pull** acting on an object. There are many different types of force, e.g. friction, air-resistance, weight , upthrust, **but they are always measured in newtons, or N.**

Sir Isaac Newton came up with three laws of motion, all of which describe the effect that forces have on things.

Before looking at these three laws, it's necessary to understand the term 'resultant force' first.

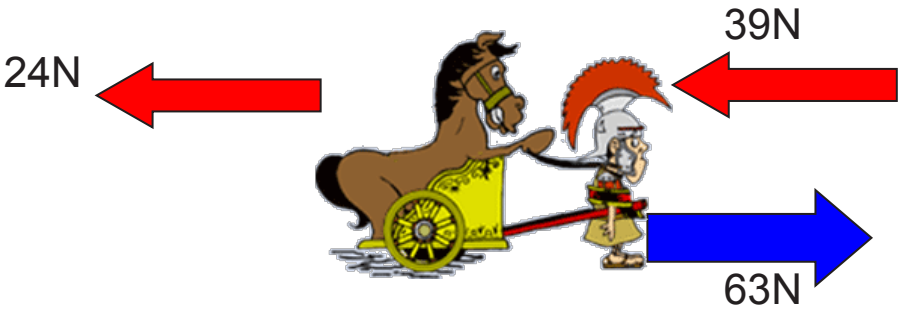
Resultant force

Usually, more than one force is acting on an object, like in the 'tug-of-war' below. In order to work out the effect of these forces on the object, we need to calculate what's known as '**resultant force**'.

Remember that all forces have a direction, unless of course they're zero.
If forces act in the same direction ➔ add; if opposite ➔ subtract.

In the above example, the **resultant force** , RF = 490 – 450 = **40N** ←

What's the **resultant** force in the example below ?



Answer : RF = 0 (zero) N, 39N← + 24N← = 63N ← (then 63-63 = 0)

Newton's laws

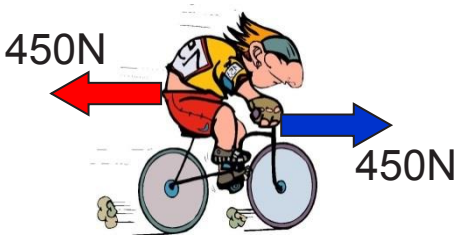
Newton's 1st law

A body will remain at rest or continue to move at a constant velocity unless acted upon by an external (resultant) force.

In effect, this is like saying that if the forces are balanced, the object will remain stationary or keep moving at a constant velocity.

In the example on the right the cyclist keeps a steady forwards force by pushing on the pedals.

If the backward forces like air-resistance are equal to the forward force, the resultant force is then zero, and so the cyclist will keep moving at a constant speed.



This law also brings about the idea of **'inertia'**. **Inertia** is the resistance of any object to any change in its motion (including a change in direction). In other words, it is the tendency of objects to keep moving in a straight line at constant speed. So, a large object with a lot of mass, e.g. a cruise ship, will be very difficult to move, accelerate, decelerate, change its direction, etc. (because of its 'inertia').

Momentum

Newton's 2nd law (see the next page) is defined using a quantity called "momentum".

Momentum is a difficult thing to explain – simply, it is how much 'motion' an object has. However, it is quite easy to calculate the momentum, **p**, of an object if you know the object's mass, **m**, and velocity, **v**, (velocity is like 'speed'). This is the equation for calculating momentum :

momentum = mass x velocity **p = m x v**

p = m x v = 3 000 x 10
= 30 000 kgm/s

p = m x v = 70 x 5
= 350 kgm/s

Docked !

p = m x v = 50 000 000 x 0
= 0 (zero !) kgm/s

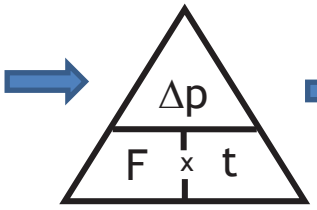
Newton's 2nd law

The rate of change of momentum is proportional to the (resultant) force applied, and takes place in the direction of the (resultant) force.

It is the **resultant** force on an object that causes a change in the speed or direction of the object. This is how it is written in equation form :

$$\text{Force} = \frac{\text{change in momentum}}{\text{time}}$$

$$F = \frac{\Delta p}{t}$$



...and the other two forms of the equation are :

$$t = \frac{\Delta p}{F}$$

$$\Delta p = F \times t$$

Force is measured in newtons, N,
time in seconds, s,
'Δp' (change in momentum) is measured in kg m/s (or Ns)

In an examination, you will typically be asked to calculate the change in momentum before using the value in the above equation. There's a worked example below .

A small rocket is launched. At a certain point in the flight, the rocket's mass is 82kg, and is travelling at a velocity of 30m/s. 10 seconds later, the mass of the rocket has reduced to 72kg, and its velocity has increased to 65 m/s. Calculate the (average) resultant force on the rocket during this 10 seconds.

Step 1 : Calculate the change in momentum, **Δp.**

Momentum at the start of the 10 s, $p_s = m \times v = 82 \times 30 = 2460$ kg m/s

Momentum at the end, $p_e = m \times v = 72 \times 65 = 4680$ kg m/s

So, change in momentum , $\Delta p = p_e - p_s = 2220$ kg m/s

Step 2 : Use Newton's 2nd law to find 'F'.

$$F = \frac{\Delta p}{t} = \frac{2220}{10} = 222 \text{ N}$$

Newton's 2nd law

In situations where the **mass** is constant, Newton's 2nd law can be simplified :

$$F = \frac{\Delta (mv)}{t} = m \frac{\Delta v}{t} = m \times a \qquad \boxed{F = m\,a}$$

So, the acceleration is directly proportional to the resultant force.
If the resultant force doubles, the acceleration doubles.

Where F = **resultant** force, m = mass, and a = acceleration

Mass & Weight

Mass is a measure of how much 'matter' or material an object has. It's measured in **kg**.

Weight is a measure of how large the force of gravity is on an object. It is measured in **N**.

Clearly, mass and weight are not the same !!

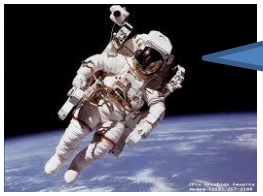
Mass does NOT depend on the location of the object, i.e. consider a 1 litre bottle of water - it has a mass of 1kg. If this bottle were taken to the surface of Mars, its **mass** would still be 1kg (as long as no water is taken out of the bottle !).

However, since there's less gravity on Mars, the **weight** of the bottle is less on Mars than here on Earth.

Since weight is a type of force, we can apply the force equation to calculate it :

$$F = m \times a$$

$$W = m \times g$$



where W = weight = 'force of gravity
m = mass
g = gravitational field strength / acceleration due to gravity

Here on the Earth's surface the value of 'g' is 10 N/kg. You will have to learn this equation, as it does not appear in the equation list at the start of the examination paper !

$$\boxed{W = m \times 10}$$

Example

A water rocket of mass 2.5kg is launched from the surface of the Earth.
It produces a steady thrust of 75N. Calculate the acceleration at the start.

Weight of rocket , W = m x g = 2.5 x 10 = 25 N

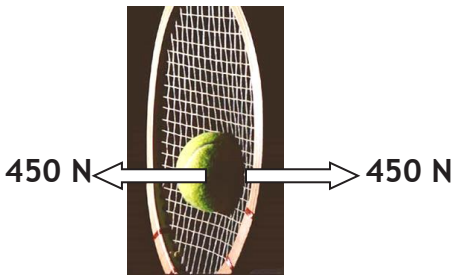
So, resultant force on the rocket = 75 – 25 = 50N (↑)

acceleration, a = $\frac{\text{resultant force}}{\text{mass}} = \frac{50}{2.5} = 20\ m/s^2$

Newton's 3rd law

In an interaction between 2 bodies, A and B, the force exerted by body A on body B is equal and opposite to the force exerted by body B on body A.

No force can act alone.
Remember that the action/reaction pair of forces are **always** on different objects, and so **never** 'cancel' out !

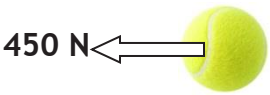


The racquet pushes the ball **forwards** with a force of 450N. Therefore, by Newton's 3rd law, the ball pushes the racquet **backwards** with an equal force.

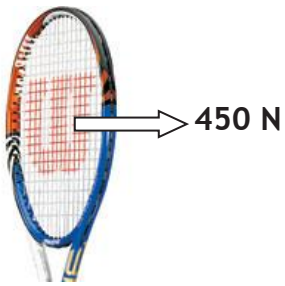
Note : one force is on the racquet, the other on the ball, so they don't 'cancel'.

The effect of these **two resultant forces** is that both objects **accelerate** in opposite directions. It may be easier to draw a **free body diagram** – a diagram that shows the forces acting on any **ONE** object at a time :

Here's the free body diagram for the tennis ball :



Here's the free body diagram for the racquet :



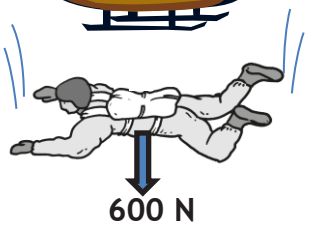
Note : Other forces like gravity and air-resistance have not been shown on these diagrams !

Applying Newton's laws

Examination questions on forces often deal with the idea of 'terminal velocity'. This idea involves a situation whereby, initially, the forces may be unbalanced (so Newton's 2nd law is used) but later become balanced (➔ Newton's 1st law).

A

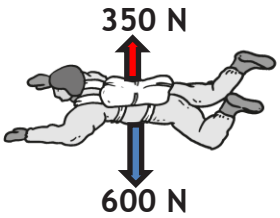
I've just jumped out of the helicopter, and so I'm hardly moving.



Air-resistance is zero, and so Newton's 2nd law states that the skydiver will **accelerate** downwards.

B

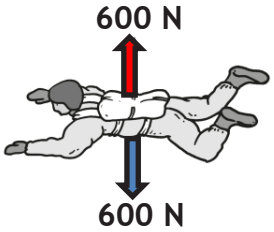
I'm now falling much faster – I can feel the air rushing past.



As the speed increases, so does the air-resistance. (The weight remains constant).Newton's 2nd law states that the skydiver will still **accelerate**, but not as much as before.

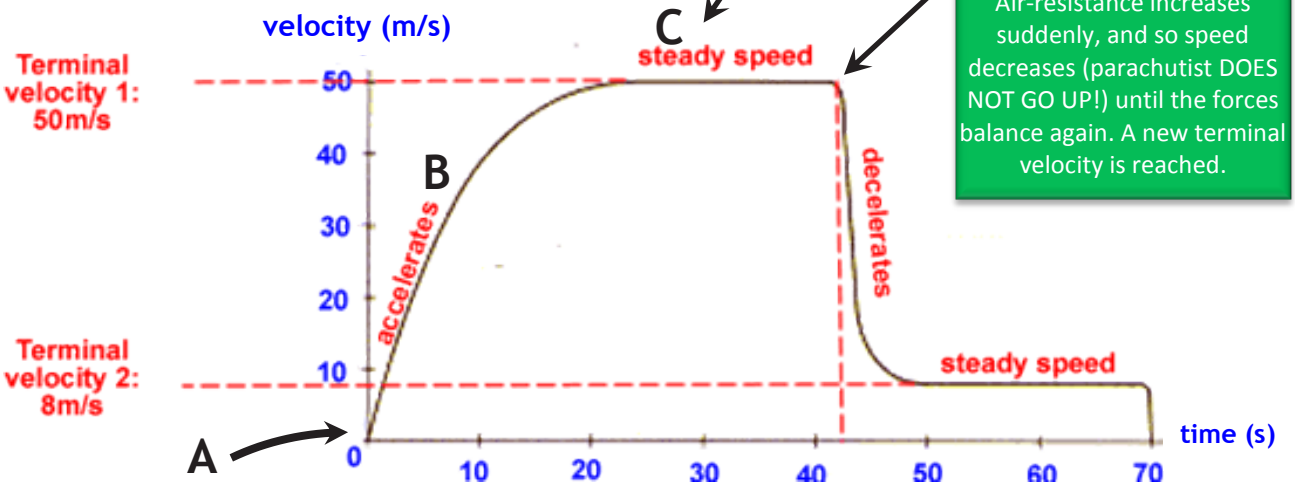
C

I'm now falling **very** fast - (about 50m/s or 115 mph !)



Eventually, the skydiver's speed is high enough such that the air-resistance is equal to the weight. Resultant force is zero, so zero acceleration. (Newton's 1st law) - **terminal velocity**

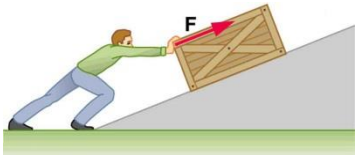
The parachute is opened here. Air-resistance increases suddenly, and so speed decreases (parachutist DOES NOT GO UP!) until the forces balance again. A new terminal velocity is reached.



Unit 3 - Work done & Energy

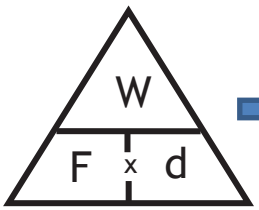
Work Done

Doing 'work' in Physics means something very specific – it means a force is acting on an object causing some energy to be transferred. Work is calculated like this :



Work done = Force x distance

W = F x d



...and the other two forms of the equation are :

F = W / d

d = W / F

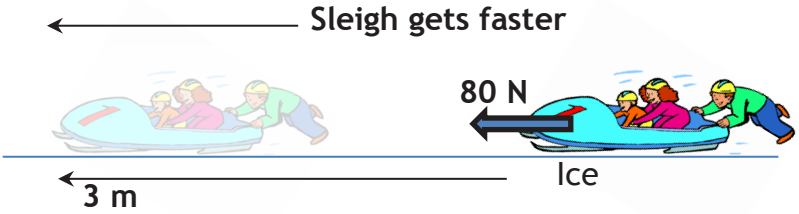
Work, W, (or energy transferred) is measured in	**joules (J)**
Force, F, is measured in	**newtons (N)**
Distance, d, is measured in	**metres, (m)**

It's very important to remember the following fact :

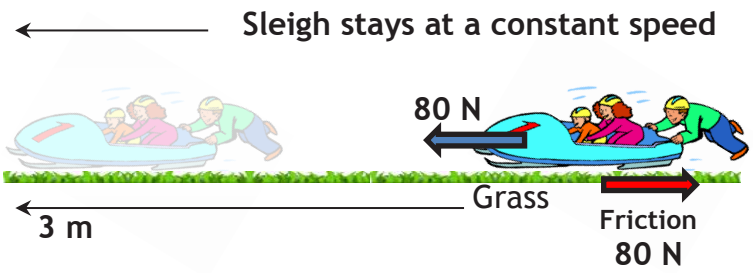
Work done = energy transferred

In correct terms, we should say that "Work done on an object is always equal to the energy transferred to or by the object". Here are 2 examples to explain this :

The force (by the person that's pushing) is doing work on the sleigh. This 240 J of work done is transferred to the sleigh, so it gains 240 J of kinetic energy - it speeds up.



The force is again doing the same amount of work on the sleigh, and so 240 J of energy must have gone somewhere !
This time, however, there's friction. The frictional force is equal to the pushing force. The work done (240 J) is transferred/wasted as heat and sound (not extra kinetic).



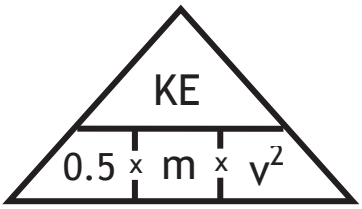
Work Done & Energy transfers

There are a number of different energy types, although all can be thought of as either kinetic or potential.

Kinetic Energy (KE) is the energy of a moving object.

Here's the equation to calculate KE :

$$\text{Kinetic energy} = \frac{\text{mass} \times \text{speed}^2}{2} \qquad KE = \tfrac{1}{2} m v^2$$



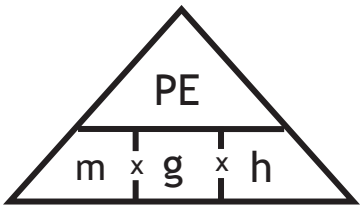
In order to find the speed of an object of known mass and KE, the above equation is re-arranged like this :

$$v = \sqrt{\frac{2\ KE}{m}} \quad \text{or} \quad \underbrace{v = \sqrt{\frac{KE}{0.5\ m}}}_{\text{Using the triangle}}$$

(Gravitational) Potential Energy (PE) is the energy an object has because of its position (usually its height above ground, or some other reference point).

Here's the equation to calculate PE :

$$\text{Change in potential energy} = \text{mass} \times \text{gravitational field strength} \times \text{change in height} \qquad PE = mgh$$



PE	is measured in	joules, J
m	is measured in	kilograms, kg
g	is measured in	N/kg (or m/s^2)
h	is measured in	metres, (m)

Work Done & Energy transfers

The **law of conservation of energy** states that energy can't be created or destroyed, only transferred from one form to another.

Hence, when an object, e.g. a ball, falls towards the ground, its gravitational potential energy (PE) decreases as it is transferred into kinetic energy (KE).

However, for all everyday situations, friction and air-resistance tend to act on moving objects, which change some of the energy into heat & sound. This is why a bouncing ball can never bounce back to the same height - some of its energy changes to heat and sound, mainly each time it strikes the floor, but also almost continuously by air-resistance.

For objects falling downwards

$$PE_{loss} = KE_{gain} + W$$

For objects thrown upwards

$$KE_{loss} = PE_{gain} + W$$

where **W** = work done by air-resistance and/or friction

Notice that the above are both 'conservation of energy' word equations. If the exam. question says that air-resistance and friction can be ignored, then just write one of the above word equation without the 'work done', '**W**'.

Also, remember that if there is some energy lost from the moving object through frictional forces, i.e. '**W**' is NOT zero, then you can also use this equation for work done :

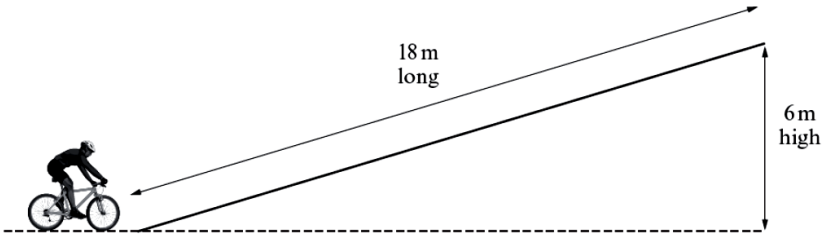
Work = Force x distance

$$W = F \times d$$

Work Done & Energy transfers

Example 1(P2, Jan 2012) - Answers at bottom of page !!

A cyclist and cycle have a total mass of 90 kg.
The cyclist reaches the bottom of a ramp at a speed of 13 m/s and stops pedalling. On reaching the top of the ramp the speed is reduced to 5 m/s.
The ramp is 18 m long and 6 m high.



(a) By using the equations

$$\text{kinetic energy} = \frac{mv^2}{2} \quad \text{and potential energy} = mgh$$

where $g = 10$ N/kg, calculate:

(i) the kinetic energy of the cyclist (and cycle) at the bottom of the ramp. [2]

Kinetic energy = ... J

(ii) the **total energy** at the top of the ramp. [4]

Total energy = ... J

(b) Use your answers to part *(a)* and an equation from page 2 to calculate the frictional force acting against the cyclist up the ramp. [3]

Frictional force = ... N

HINTS !!

Simply add the KE_{top} and the PE.

Find the difference between the energy of the cyclist at the bottom and at the top – this 'difference' is equal to the **work done** by frictional forces.

Answers

(a) (i) $KE_{bottom} = 0.5\ m\ v^2 = 7610$ J
(ii) $E_{total} = KE_{top} + PE = 1130 + 5400 = 6530$ J

(b) **Expected method**

$W_{friction} = KE_{bottom} - E_{total} = 1080$ J
Friction $= W_{friction}$ / distance $= 60$ N

(b) **Alternative method**

$KE_{loss} = PE_{gain} + W_{friction}$
hence, $W_{friction} = KE_{loss} - PE_{gain} = 1080$ J

Friction $= W_{friction}$ / distance $= 60$ N

Example 2 (P2, June 2012) - Answers at bottom of page !!

A cruise ship's engines produce a constant thrust of 1.6×10^6 N. It has a mass of 1.2×10^8 kg.

(a) Use the equation

$$\text{acceleration} = \frac{\text{resultant force}}{\text{mass}}$$

to calculate the ship's initial acceleration. [2]

Acceleration = ... m/s^2

(b) Once at sea, the ship's speed increases from 5 m/s to 9 m/s over a distance of 2400 m. By using the equations

$$\text{work} = \text{force} \times \text{distance}$$

$$\text{kinetic energy} = \frac{\text{mass} \times \text{speed}^2}{2}$$

(i) calculate the work done by the ship's engines over the 2400 m travelled at sea, [2]

Work done = ... J

(ii) calculate the increase in the ship's kinetic energy. [2]

K.E. increase = ... J

(iii) Use your answers to parts (i) and (ii) to calculate the mean work done against the ship as its speed increases. Hence find the value of the mean drag force acting against the ship. [3]

Mean work done = ... J

Mean drag force = ... N

HINTS !!

'Initial acceleration' means 'at the start', when the ship isn't moving fast enough to experience any friction or air-resistance. This means that you can assume the resultant force is equal to the 'thrust'.

Look up the equation for 'work done'.

Calculate the KE **twice** - once for each speed, then find the difference.

Calculate the difference between the work done by the engines and the KE gain. This is the work done by the frictional forces.

Answers

(a) $a = 0.013\ m/s^2$

(b) (i) $W_{engine} = 3.84 \times 10^9$ J

(ii) $KE_{gain} = KE_{final} - KE_{initial} = 3.36 \times 10^9$ J

(iii) $W_{drag} = 4.80 \times 10^8$ J ; hence, **Drag** = W_{drag} / distance = 2.00×10^5 **N**

Stopping distance & Car Safety

Many road accidents happen because people often underestimate the distance needed to slow a car until it stops – **the stopping distance.**

The stopping distance is in two distinct parts :

Stopping distance	=	**Thinking distance**	+	**Braking distance**

Thinking distance = **the distance travelled whilst reacting to a situation (before the driver applies the brakes)**

Braking distance = **the distance travelled whilst the brakes are applies (car is slowing down)**

Reaction **time** is closely linked to thinking distance as follows :

Thinking distance = speed x reaction time (d = s x t)

So, although a person's reaction time is not much affected by speed, the thinking distance is – look at these calculations at two different speed, 20 m/s, and 40 m/s, with a typical reaction time of 0.4 s,

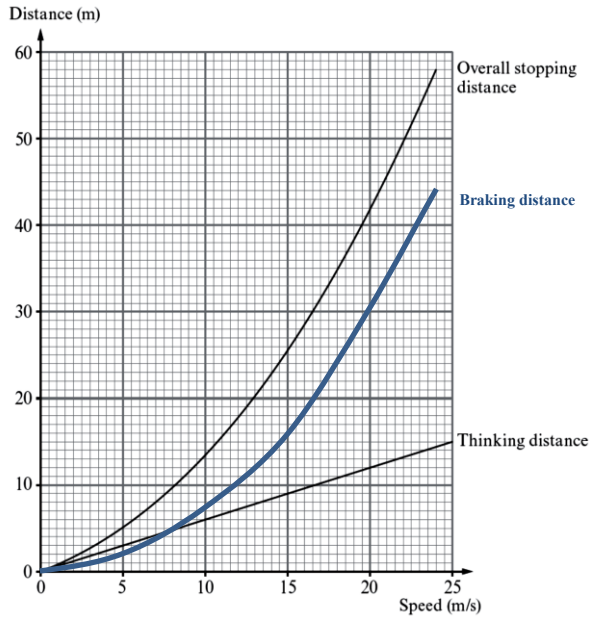
@ 20 m/s	Thinking distance	=	20 x 0.4	=	8m
@ 40 m/s	Thinking distance	=	40 x 0.4	=	16m

So, thinking distance is directly proportional to the vehicle's speed.

Braking distance also increases with the vehicle's speed. However, they're not proportional (see the blue line on the graph ➔).

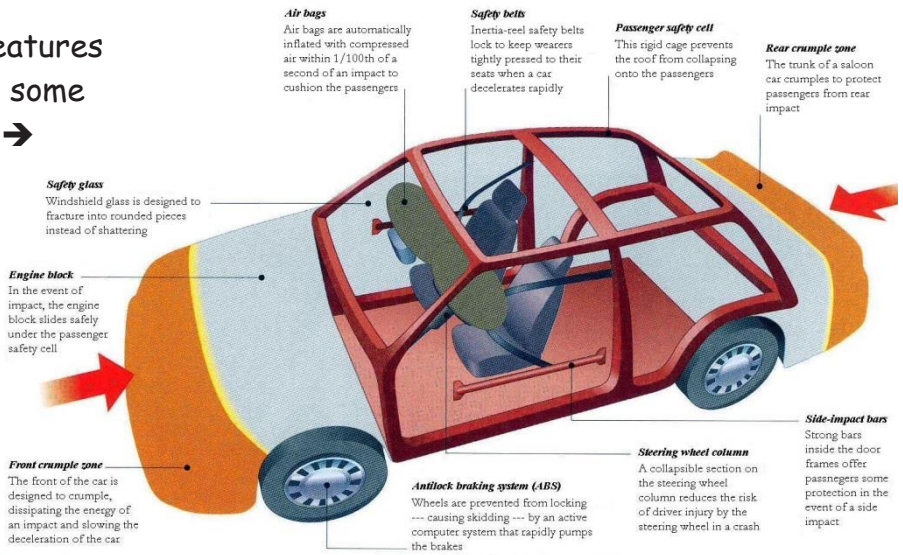
(In fact, doubling the vehicle's speed quadruples the braking distance, since the speed is squared in the KE equation).

To find the overall stopping distance at a particular speed, just add the thinking distance and the braking distance values at that speed.



Stopping distance & Car Safety

There are many safety features in modern cars/vehicles – some are shown in the picture. ➔

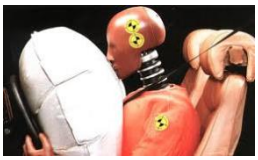


The main features are :

1) Seat belts
2) Crumple zones
3) Airbags
4) Side-impact bars
5) Passenger cell

Feature	What it is	How it works
Seat belt	A strong belt strapped around the body	Prevents the person being thrown forwards in a crash
Crumple zone	A section that deforms/compresses on impact	Decreases the deceleration, and so the force
Airbag	A bag that inflates rapidly in front of the person during a crash	Acts as a cushion to prevent the head of the passenger from hitting the front/side of the inside of the car
Side-impact	Strong bars inside the car doors	Strengthens the doors to better protect the passengers from another car hitting from the side
Passenger cell	A rigid cage around the passengers	Protects the passengers from impacts in all directions, but especially from a collapsing roof (when the car's upside-down)

Car manufacturers intentionally crash cars with dummies inside to assess the effectiveness of various safety features.



The idea behind crumple zones and airbags is to reduce the **force** on passengers during a crash.

Force = mass x acceleration

Since your mass is fairly constant, the only way to reduce the force is to reduce the **acceleration (or deceleration).** There are two ways of reducing the deceleration :

1. If the vehicle's speed is less, then less deceleration is needed to stop it !
2. The deceleration is less if the change in speed happens over **more** time.

The safety devices mentioned work by ensuring that you take **more time** to slow down. Remember the following reasoning :

Change the speed over **more** time. ➔ Less deceleration ➔ Less force

Unit 4 - Electricity

Simple electrical circuits.

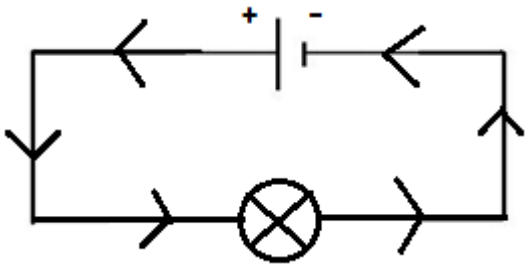
Device	Symbol	Device	Symbol
Wire		Cell / Battery	
Power Supply	+ −	Bulb	
Open switch (Off)		Closed switch (On)	
Diode		Resistor	
Variable resistor		Motor	M

Electrical current (I)

Current is the flow of free electrons (negatively charged). As a comparison, think of measuring the amount of water flowing through a pipe.

- Current is described as a measure of the charge that flows past a point every second.

  It flows from **+** **to** **−** .



- Current is measured in **Amperes, A.**
- It is measured using an **Ammeter connected in series.**

Voltage (V)

Voltage is a measure of how much electrical energy a certain amount of electrons can transfer as they flow around a circuit. The higher the voltage, the more electrical energy is supplied to the circuit.

- Voltage is measured in **Volts, V.**
- It is measured using a **Voltmeter connected in parallel.**

Resistance (R)

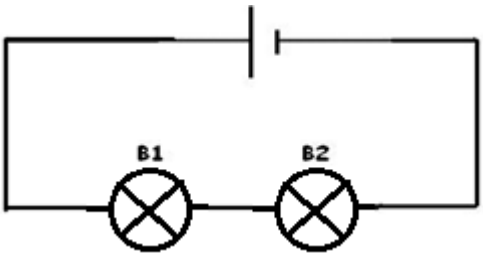
Resistance is a measure of how difficult it is for current to flow through a wire or device. More resistance means less current because it is more difficult for it to flow. Resistance is caused due to the collisions between the free electrons and the atoms/ions in the metal.

- Resistance is measured in **Ohms – Ω.**
- A thin wire has more resistance than a thick wire.

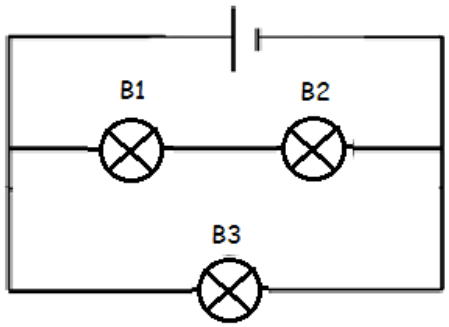
Name	Unit	Measured using	Symbol	Connected in…
Current	*Amps – A*	*Ammeter*	A	*Series*
Voltage	*Volts – V*	*Voltmeter*	V	*Parallel*
Resistance	*Ohms - Ω*			

Series and Parallel circuits.

Series circuit: in a series circuit there is only path and the bulbs (B1 and B2) in the diagram below are one after the other. If bulb B1 breaks then B2 will not work/go off.

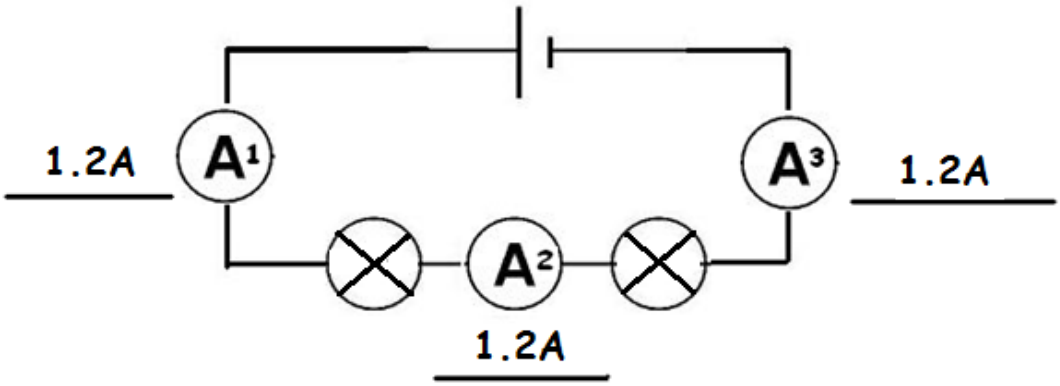


Parallel circuit: in a parallel circuit there is more than one path and the circuit is divided into branches. Bulbs B1 and B2 are in series but B3 is in parallel with them. If bulb B3 breaks then B1 and B2 will continue to work.



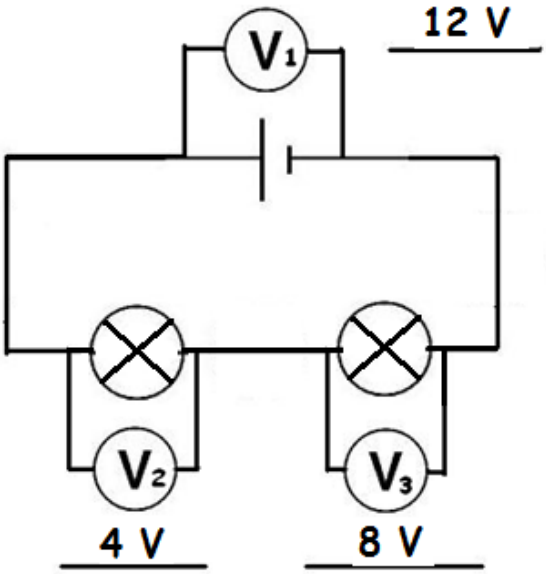
Measuring current and voltage in circuits.

Current in series circuits: ammeters must be connected in series i.e. in the circuit.



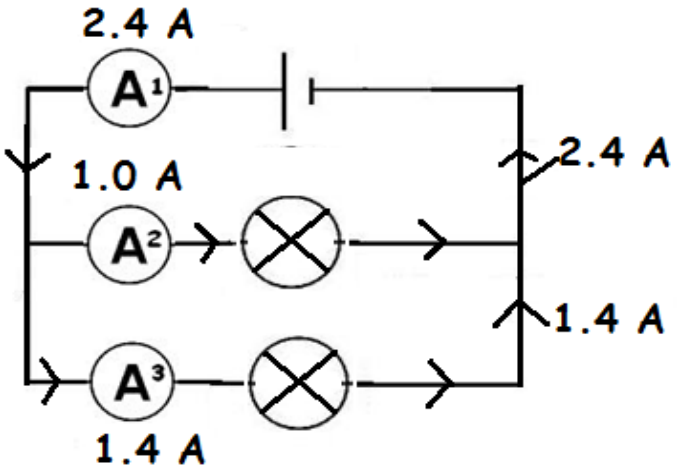
The value of the current is the same at all points ($A_1 = A_2 = A_3$) in the circuit since there is only one path for the current to flow.

Voltage in series circuit: the voltmeters are connected across the component e.g. bulb or battery.



The voltage across both components/bulbs here adds up to the voltage across the supply/battery i.e. ($V_1 = V_2 + V_3$) or (12 = 4 + 8).

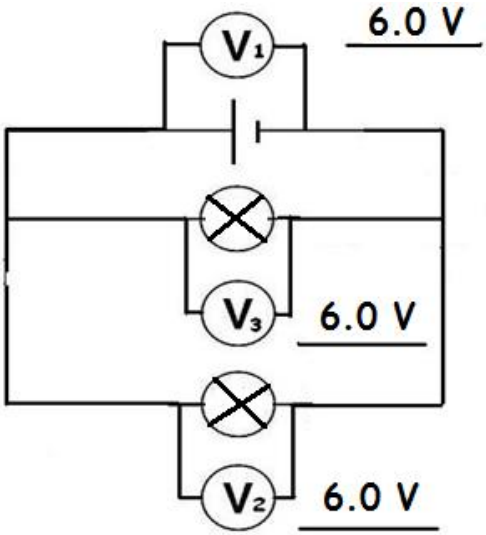
Current in parallel circuits: the ammeter in this series circuit is connected in series.



The value of the current in the two branches adds up to the total current flowing, i.e. ($A_1 = A_2 + A_3$) or (2.4 = 1.0 + 1.4).

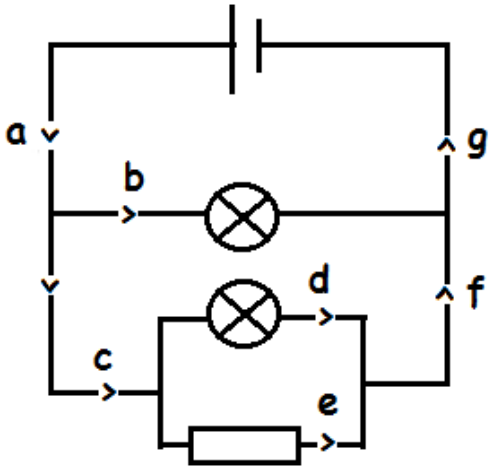
Voltage in parallel circuit: the voltage across all components in parallel is the same.

i.e. ($V_1 = V_2 = V_3$)



Predicting current values.

What is the value of the current at the following points in the circuit.



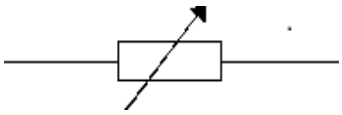
Point	Current (A)
a	3.6
b	2.0
c	
d	1.2
e	
f	
g	

Answers; c = 1.6A, e = 0.4 A, f = 1.6A, g = 3.6A

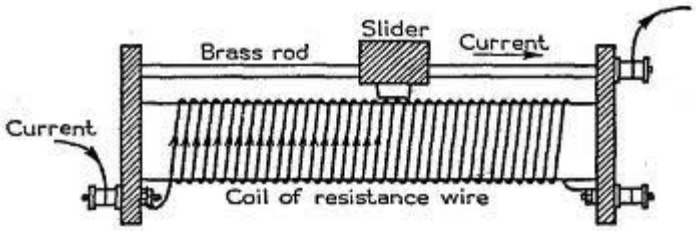
Variable resistors (controlling the current).

In your house the mains voltage is 230V. Not all devices require the same current to operate and some will have two or three settings (like a toaster or hairdryer) so we must have a way of changing/controlling the current required.

A variable resistor (rheostat) is a resistor for which it is possible to alter/vary the resistance. Variable resistors are components that can be put into a circuit to control the current and the voltage e.g. volume control and dimmer switch



If you look at the variable resistor below then the more the slider is over to the right hand side the more wire the current has to go through so the greater the resistance and therefore the current decreases.

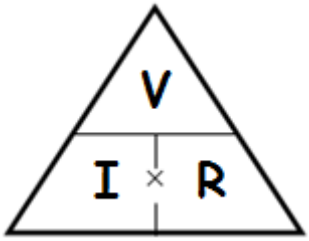


Wire-wound rheostat

Ohm's law

This law describes the relationship between voltage (V), current (I) and resistance (R).

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}}$$



$$R = \frac{V}{I} \quad \text{or} \quad V = I \times R \quad \text{or} \quad I = \frac{V}{R}$$

e.g. Calculate the voltage across a 15Ω resistor that carries a current of 1.8A.

V = 1.8 x 15 = 27 V

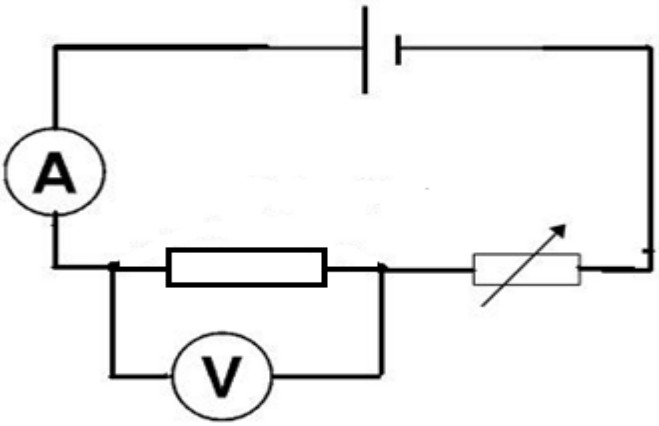
Q1. Calculate the current through a 2kΩ resistor when there is a voltage of 230V across it.

Q2 An electric fire with 4A flowing through it has a voltage of 230V across. Calculate the resistance of the wire in the electric fire.

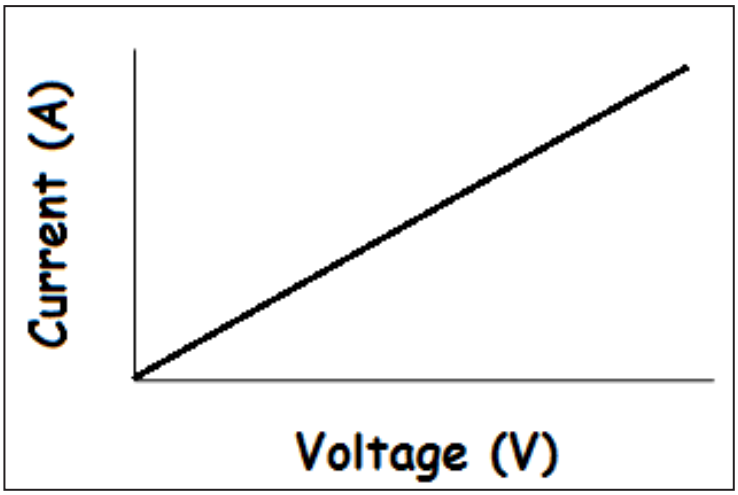
Answers: Q1 = 0.115 A , Q2 = 57.5 Ω

Current – voltage relationship

Resistor or wire at constant temperature. Moving the variable resistor changes the resistance of the circuit so that you can then change and measure the voltage across the resistor/wire and the current flowing through it.



A graph of the voltage and current are plotted. Key features of the graph are:



- The graph shows that if the voltage across the wire/resistor is doubled then the current also doubles.
- The relationship between the current and voltage is **directly proportional**. The relationship is only directly proportional if the graph goes through the origin (0,0) and is a straight line.
- This only happens if the **temperature of the wire remains constant**.
- The constant gradient of the graph means that the ***resistance remains constant*** and that the resistor/wire ***obeys Ohm's law.***

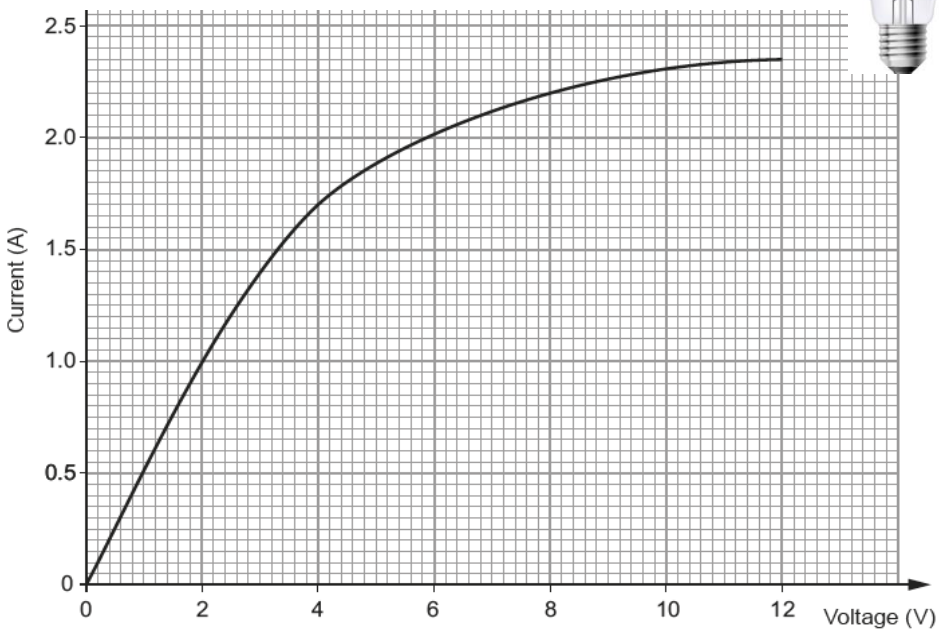
Changing resistance

$$\text{Resistance} = \frac{\text{voltage}}{\text{current}} \quad \text{or} \quad R = \frac{V}{I}$$

If the voltage remains constant then if the resistance of ***resistor/wire doubles*** then the ***current will halve.*** This relationship is ***inversely proportional.***

Filament lamp (NOT constant temperature). The same circuit as for the resistor/wire is used, except the resistor is changed for a bulb.

- Up to 2V the current and voltage increase at the same rate because the resistance is constant (constant gradient).
- From 2V to 12V the current increases at a slower rate than the voltage.
  The gradient is not constant so the **resistance is not constant.**



The ***resistance of the lamp increases*** because the temperature of the filament wire is increasing. Therefore the filament lamp does **NOT** obey Ohm's law.

Calculate the resistance of the lamp at (i) 2 V (ii) 12 V.

$R = \frac{V}{I}$ (i) $R = \frac{2.0}{1.0} = 2.00\ \Omega$ (ii) $R = \frac{12.0}{2.35} = 5.11\ \Omega$

Electrical Power.

This is the **rate** (per second) of energy transfer i.e. the amount of energy a device can transform from one form to another per second e.g. The power of a light bulb is the amount of electrical energy it can transform from electrical energy to heat and light every second.

Power is measured in WATT, W. Equation, **Power = Voltage x current, P = V x I**

Device	**Power (W)**	**Energy transferred every second. (J/s)**	**Energy transferred into heat every second. (J/s)**	**Energy transferred into light every second. (J/s)**
Filament bulb	60.0	60.0	56.0	4.0
CFL (energy saving) bulb	11.0	11.0	4.0	7.0
LED bulb	6.0	6.0	0.4	5.6

Power, current and resistance.

If we want to calculate the power consumption of an electrical component in a circuit but we do not know the voltage then we can do so by combining two equations.

Power = Voltage x Current *substitute* **Voltage = current x resistance**

$P = V \times I$ $V = I \times R$

$$P = V \times I \longrightarrow P = (IR) \times I \longrightarrow P = I^2 \times R$$

Power = current^2 x resistance

Example: A 2kΩ resistor has a current of 0.80A flowing through it. Calculate the power of the resistor. First we must change 2kΩ into Ω by multiplying by 1000.

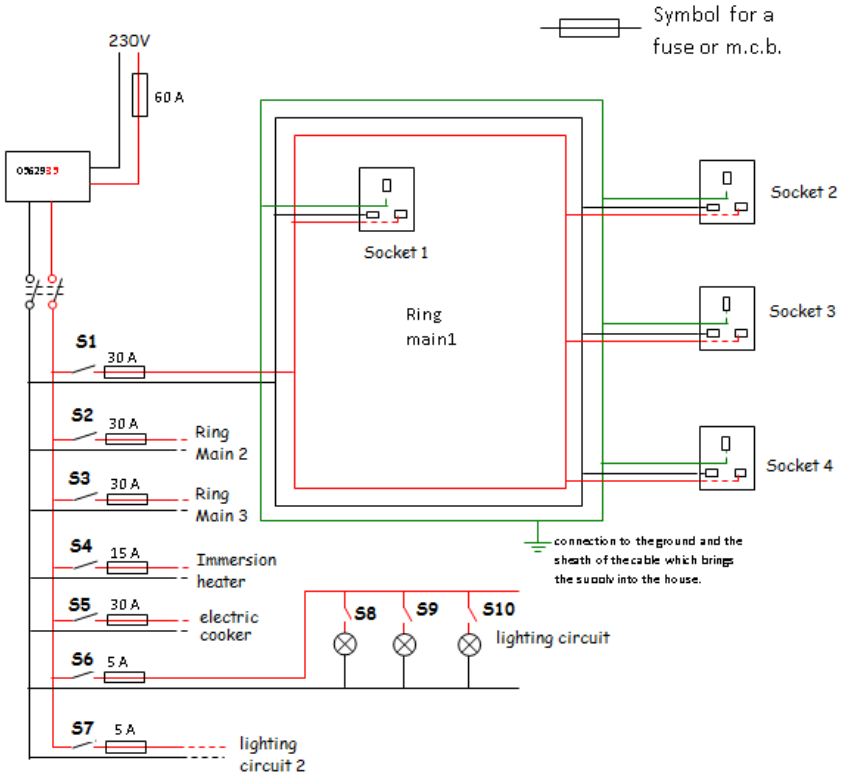
Resistance in Ω = 2 x 1000 = 2000 Ω then, Power = current^2 x resistance

= 0.8^2 x 2000

= 1280 W

Circuits in the home. (Ring Main)

The diagram shows the type of electrical circuit used in your home.



1. What is the voltage across socket 1? Answer= 230 V

2. Which switch would you use if you wanted to do maintenance work on ring main1? Answer = S1

3. What is the maximum power that could be supplied to the electric cooker?

P = V x I

= 230 x 30

= 6900 W

4. There are 3 identical bulbs in the lighting circuit, and they each require a current of 0.05A. Calculate the total power of the 3 bulbs.

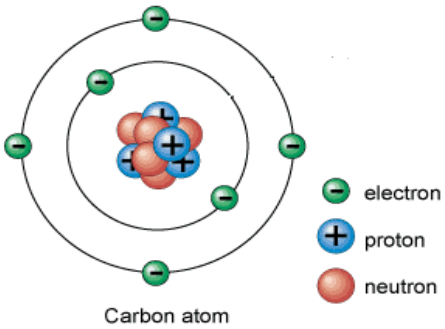
Total current for all bulbs = 0.05 + 0.05 + 0.05 = 0.15 A

Power = voltage x current = 230 x 0.15 = 34.5 W

Unit 5 - Nuclear Physics

Nuclear physics.

To understand what radioacivity is you must understand what makes an atom radioactive.



The atom consists of:

6 protons

6 neutrons

6 electrons

^{A}X where X is the symbol for the element

Proton number (or Atomic number) (Z) - This tells us the ***number of protons*** in the atom/nucleus.

Nucleon number (aka Mass Number) (A)– This tells us the number of ***protons and neutrons*** in the atom/nucleus.

A mathematical formula to calculate the number of neutrons 'N' in terms of A and Z.

$$N = A - Z$$

Example: $^{7}_{3}Li$

Number of protons = 3

Number of neutrons 'N' = A – Z = 7 – 3 = 4

Try the following examples.

Element	Proton (Z) number	Nucleon (A) number	Number of protons	Number of neutrons, N
Hydrogen	1	1		
Iron	26	56		
Uranium	92	235		

Isotopes: These are atoms of the same element which have the same number of protons but a different number of neutrons. They have the same proton number and differing nucleon number.

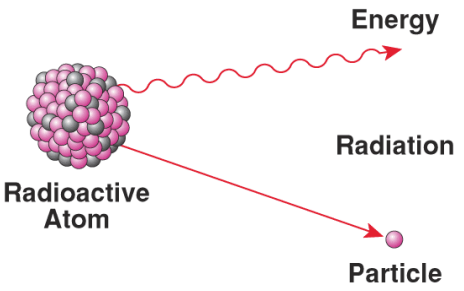
Example. Iodine-123 $^{123}_{53}I$ and iodine-131 $^{131}_{53}I$ are isotopes. Iodine-123 has 53 protons and 70 neutrons whereas iodine-131 has 53 protons and 78 neutrons.

The higher the proton number of the element the more neutrons the element will have compared to protons.

RADIOACTIVE DECAY.

Why is an atom radioactive? ***If an atom has an imbalance of protons and neutrons in the nucleus it will be also be UNSTABLE.***

(This does **not** mean an equal number of protons and neutrons).



The nucleus tries to become stable by breaking up into stable fragments: **RADIOACTIVE DECAY**. Carbon has three common isotopes ^{12}C, ^{13}C a ^{14}C. Carbon-14 is radioactive because it has an ***imbalance of protons and neutrons.***

$$^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

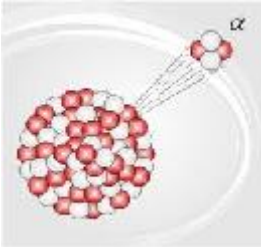
Carbon will **emit radiation** to try and make itself stable, a nitrogen nucleus is formed in the process. This process is called **RADIOACTIVE DECAY**.

There are 3 types of radiation emitted from the nucleus.

Information	**Alpha (α)**	**Beta (β)**	**Gamma (ɣ)**
Symbol	$^{4}_{2}He$	$^{0}_{-1}e$	ɣ
What is it?	A helium nucleus (2 protons and 2 neutrons).	Fast moving/ high energy electron.	High energy electromagnetic wave.
What can stop it? Penetrating power.	Thin sheet of paper, skin or few cm of air	Few mm of aluminium or up to a metre of air.	Several cm of lead or very thick concrete.
Ionising power	Very high – most damaging inside the body.	Medium	Low (compared with alpha and beta). Easily passes through the body.

Balancing nuclear equations.

Alpha decay $^{4}_{2}He$



During alpha decay the number of protons decreases by 2 and the number of neutrons decreases by 2. Therefore the proton number decreases by 2 and the nucleon number decreases by 4.

General equation:

$$^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}X + {}^{4}_{2}He$$

$$^{238}_{92}U \longrightarrow {}^{234}_{90}Th + {}^{4}_{2}He$$

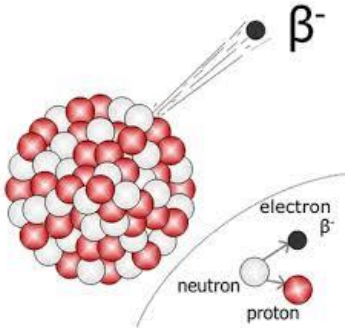
Balance the following nuclear equations by calculating the value of a, b, c and d.

1. $^{241}_{95}Am \longrightarrow {}^{a}_{b}Np + {}^{4}_{2}He$

2. $^{236}_{84}Po \longrightarrow {}^{c}_{d}Pb + {}^{4}_{2}He$

a=237, b=93, c=232, d=82

Beta decay.



During beta decay the number of protons increases by 1 and the number of neutrons decreases by 1. Therefore the proton number increases by 1 and the nucleon number stays the same

General equation:

$$^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}X + {}^{0}_{-1}e$$

$$^{16}_{8}O \longrightarrow {}^{16}_{9}F + {}^{0}_{-1}e$$

Balance the following nuclear equations by calculating the value of a, b, c and d.

1. $^{a}_{b}H \longrightarrow {}^{2}_{2}He + {}^{0}_{-1}e$

2. $^{63}_{28}Ni \longrightarrow {}^{c}_{d}Cu + {}^{0}_{-1}e$

a=2, b=1, c=63, d=29

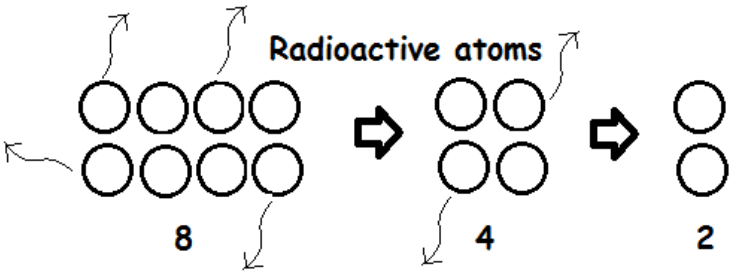
Half life.

There are billions upon billions of atoms in a small amount of a radioactive sample so the chance that one atom will undergo decay is high.

Is it possible to determine **which** radioactive nuclei/atom will decay next in the sample? No, because the process is **random**. Is it possible to determine when the next radioactive nuclei will decay? No, because the process is **spontaneous**. Since its random and spontaneous process we can get more accurate information/results by:

1. Repeating. 2. Measuring over a long time.

<u>The half life.</u> Each half life the number of atoms halves. The half life remains constant.



The half life is the time it takes for half the unstable atoms to decay.

The half life is the time it takes for the activity to halve from its original value.

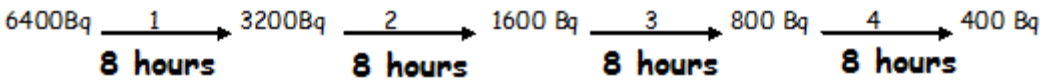
Actvity. The activity is a measure of number of radioactive decays per second. It is measured in **becquerel, Bq.** So an activity of 1 bequerel is equivalent to 1 radioactive decay per second. The activity of a sample of radioactive material will depend on 2 things:

1. The number of radioactive/unstable atoms present.

2. The half life of the atoms.

The more atoms present the greater the activity. The shorter the half life the greater the activity.

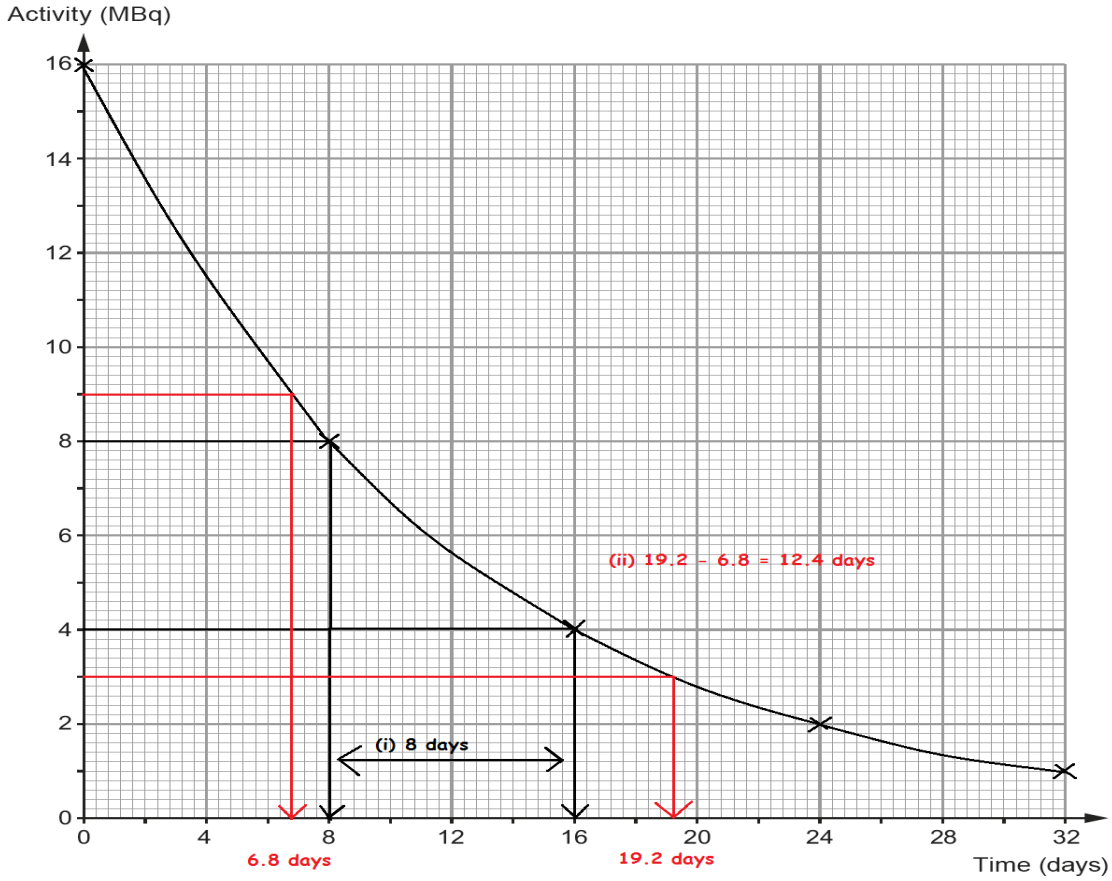
Example. A radioactive isotope has an activity of 6400Bq.The half life of the isotope is 8 hours. What is its activity after 32 hours?



There have been 4 half lives totalling 32 hours (8 hours x 4).

Radioactive decay curves.

Whether you are plotting a graph of activity or the number of radioactive atoms the curve/line of the graph is the same.
In this example the activity of the isotope iodine-131 has been plotted against time. The sample has a starting/initial activity of 16 MBq (16,000,000Bq)



(i) We can calculate the half life using the method shown above. You must choose one activity and then halve it. In the example the activity has halved from 8MBq to 4MBq. This has taken 8 days so we can say that the **half life of iodine-131 is 8 days.**

(ii) We can also calculate how long it will take for the activity to fall from 9 MBq to 3 MBq.
The activity was 9 MBq after 6.8 days and the activity was 3 MBq after 19.2 days.
Therefore by calculating the time difference in we can calculate how long this took.
19.2 – 6.8 = **12.4 days.**

(iii) How long would it take for the activity to fall from 1 MBq to 250,000 Bq?

It is not possible to continue the graph so we must use the same method as on the previous page.

1 MBq = 1,000,000 Bq $\xrightarrow[\text{8 days}]{1}$ 500,000 Bq $\xrightarrow[\text{8 days}]{2}$ 250,000 Bq

Total time = 8 + 8 = 16 days

Uses of radioactive materials.

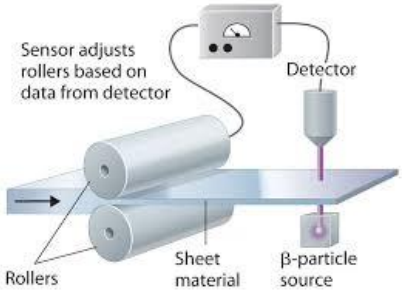
There are many uses of radioactive materials; carbon dating, sterilising medical equipment, killing cancer cells, smoke alarms and controlling the thickness of aluminium foil.

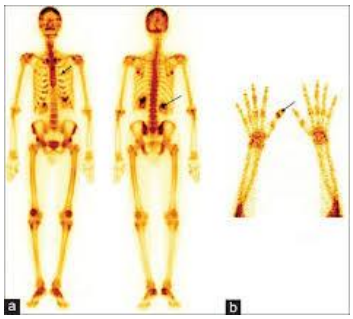
What is required is that you can select from a given list and explain which isotope is suitable for use in a specific case. Consider the ***type of radiation*** emitted and the ***half life.***

In this case we will choose one of the isotopes for a particular use and explain our reasoning.

Example of radioactive isotope. The half life given in brackets ( )		
Gamma – γ	**Beta** $_{-1}^{0}e$	**Alpha** $_{2}^{4}He$
Technetium-99 (6.01hrs) Cobalt-60 (5.27 yrs)	Iridium-192 (74 days) Strontium-90 (28.5 yrs) Carbon-14 (5730yrs)	Polonium-210 (138days) Americium-241 (432 yrs) Plutonium-238 (87.7 yrs)

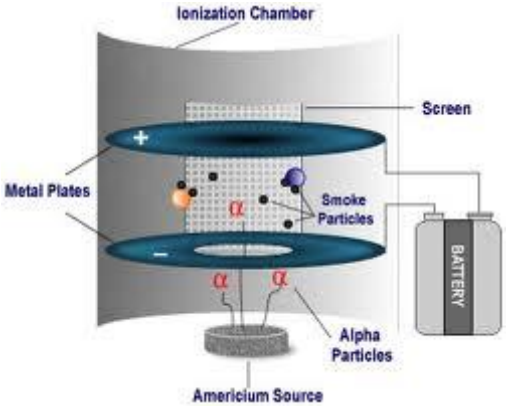
(a) Monitoring the thickness of aluminium sheet in a factory.
Isotope: Strontium – 90 (beta emitter).
Reason: because **fewer** beta particles will pass through when the thickness of aluminium increases. The half life is fairly long so the source will last a reasonable amount of time.





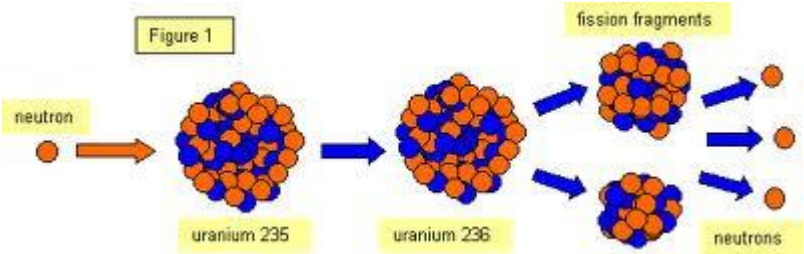
(b) Medical tracer in monitoring internal organs by using a camera outside the body.
Isotope: Technetium-99 (γ – emitter)
Reason: because it's a gamma emitter, it passes out of the body easily. The half life is short so it will not remain in the body for a long time.

(c) A smoke detector.
Isotope: Americium-241 (alpha emitter)
Reason: Gamma more penetrating than alpha so it would not be blocked by smoke. It has a longer half life so detector stays active / keeps working for a longer period of time. Polonium-210 has too short a half life so it would not last very long and therefore it's not suitable



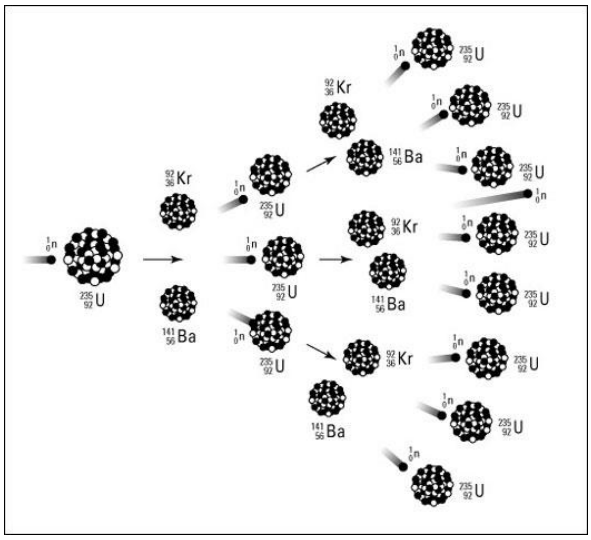
Nuclear Fission

Nuclear fission. This is a decay process in which an unstable nucleus splits into two fragments of comparable mass or to put it another way it is the splitting of a heavy nucleus into two lighter nuclei.



Most elements need to be stimulated to undergo fission; this is done by bombarding them with neutrons. The process is called ***induced fission.*** Fission of uranium-235 will occur when it absorbs a **slow moving neutron**, making the resulting nuclide ^{236}U, unstable. The ^{236}U is in a highly excited state and splits into two fragments almost instantaneously.

Uranium Isotopes. There are two main isotopes of uranium – uranium-238 and uranium-235. Uranium which is mined is 99.3% U-238 and only 0.7% U-235. This uranium must be enriched to make bombs, which means increasing the amount of U235 present. In nuclear reactors the uranium is only slightly enriched. Uranium-238 and uranium-235 are radioactive.



Chain reaction. During fission of uranium-235 neutrons are emitted as fission products. A large amount of **energy** is released.

Sustainable fission involves one of the neutrons causing further decay. Just because it's a chain reaction it does **not** mean that it will result in an explosion.

Balancing fission nuclear equations. When uranium-235 undergoes fission the same products/nuclei are **not** produced each time.

Example

$$1\ {}^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{135}_{52}Te + {}^{97}_{40}Zr + 4\ {}^{1}_{0}n$$

Left: total A = 235 + 1 = 236

Total Z = 0 + 92 = 92

Right: total A= 135 + 97 + (4 x 1) = 236

Total Z = 52 + 40 + (4 x 0) = 92

The total A (nucleon) and Z (proton) numbers on both sides must be equal/the same.

Balance the following nuclear equations by calculating the missing numbers (letters a, b, c and d)

1. $$1\ {}^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{a}_{56}Ba + {}^{92}_{b}Kr + 3\ {}^{1}_{0}n$$

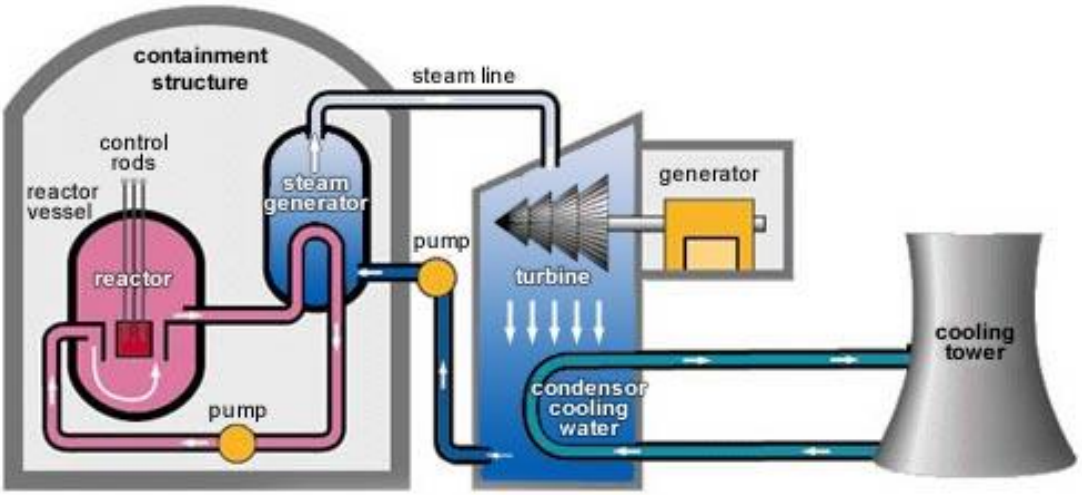
2. $$1\ {}^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{140}_{c}Xe + {}^{94}_{38}Sr + d\ {}^{1}_{0}n$$

The fission fragments are themselves unstable.

a = 141, b = 36, c = 54, d = 2

Nuclear Reactor

In a thermal nuclear reactor the chain reaction is steady and controlled (hopefully) so that on ***average only one neutron, from each fission produces another fission.***



Control rods and the moderator.

Moderator

The moderator **slows down neutrons** to allow them cause further fission. The neutrons released in the fission of U-235 are not fast enough to cause fission in U-238 but fast enough to be captured. So in a thermal reactor, the neutrons must be slowed down so that they avoid capture by the U-238 and cause fission in U-235.

The **moderator** surrounds the fuel rods and is used to slow down the neutrons. Most nuclear reactors use water as a moderator whilst some use **graphite rods**. The advantage of using **water** as a moderator is that is can also be used as the coolant to transfer the heat energy away from the reactor to generate electricity. However if the **coolant** is lost, (as happened in Fukushima in Japan tsunami March 2011) the neutrons will not be slowed down and so the nuclear chain reaction stops but this loss of coolant cause the reactor to **overheat**.

Control Rods.

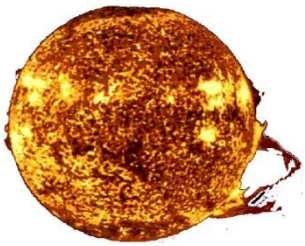
They can use **control rods** to stops/control the number of thermal neutrons inside the fuel rods/reactor. This alters the rate (number of fission reactions per second) at which nuclear fission takes place. The control rods **absorb** the neutrons thus preventing them from causing further fission in U-235. Metals such **boron** and **cadmium** are used to make the control rods. If a fault occurs then the **control rods should drop into the reactor** automatically thus stopping the chain reaction. By moving the control rods down the chain reaction is slowed down (more thermal neutrons absorbed) and it can be speeded up by moving the control rods up (fewer neutrons absorbed).

Steel is used as a material for the pressurised **reactor vessel** which is then surrounded by thick walls of **concrete**. The steel vessel is pressurised to prevent the water from boiling but can be dangerous if overheating occurs, causing the vessel to explode. The water in the vessel is not the same water which is used to drive the turbine.

Unfortunately the **fission products** e.g. Barium, Krypton, Caesium and Iodine, which are contained within the fuel rods, are also radioactive and many have very **long half-lives**. They are radioactive because they have a too many neutrons and so usually undergo beta decay. Once the uranium-235 has been used up in the fuel rods they must be stored safely under water in **cooling ponds**. This allows them to cool down safely, without their radiation escaping from the building. The water also provides some **shielding** from the radiation. The used fuel rods spend many years in the cooling ponds after which they are sent to places like Sellafield in Cumbria to be reprocessed.

Nuclear Fusion

Fusion: When two smaller nuclei are joined together to form a larger one. A Large amount of **energy** is released in the process.



In the Sun fusing two hydrogen nuclei is possible because of the high pressure and they are moving at such high speeds due to the very high temperature at the core of 15,000,000°C.

They are experimenting with fusing light elements together. Two isotopes of hydrogen – ***deuterium*** $^{2}_{1}H$ (1 proton, 1 neutron) and ***tritium*** $^{3}_{1}H$ (1 proton, 2 neutrons) can undergo fusion to form helium and a neutron.

This is a nuclear equation for the reaction.

$$^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n$$

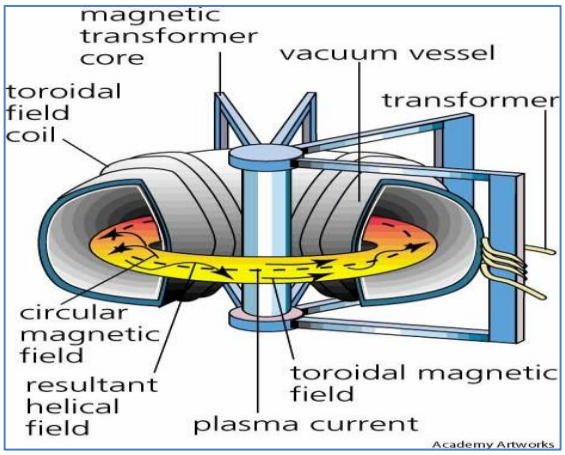
Total A = 2+3 = 5 | Total A = 4 + 1 = 5

Total Z = 1 + 1 = 2 | Total Z = 2 + 0 = 2

Equation Balanced

A good source for the hydrogen isotopes would be **sea water.**

Achieving controlled fusion on Earth.



Containment is in a doughnut shaped reactor. Deuterium and tritium are heated to very high temperatures, using large currents to form a plasma (ionised gas). The strong magnetic field contains and accelerates the particles to very high speeds so that they can collide with enough energy to undergo nuclear fusion. The neutron that is produced has a large amount of kinetic energy which can be used to generate heat and then generate electricity.

The **neutrons** that are generated can be captured by atoms in the reactor making them unstable and therefore **radioactive.** The reactor must therefore be **shielded** using concrete to prevent any radiation escaping and so protect the workers.

Comparing fission and fusion.

Power source	Advantage	Disadvantage
Nuclear Fusion	• Abundant source of deuterium and tritium in sea water.  • Does not produce greenhouse gases. • No long lived radioactive materials produced.	• High temperature required. • Pressure containment of the plasma.  • Shielding of neutrons using concrete • High energy input required.
	Advantage	Disadvantage
Nuclear Fission	• Does not produce greenhouse gases. • Large amount of power produced. • Uses small amount of fuel.	• Radioactive material produced with long half life. • Risk of nuclear meltdown.  • Cost of decommissioning the power station and storing of waste material.