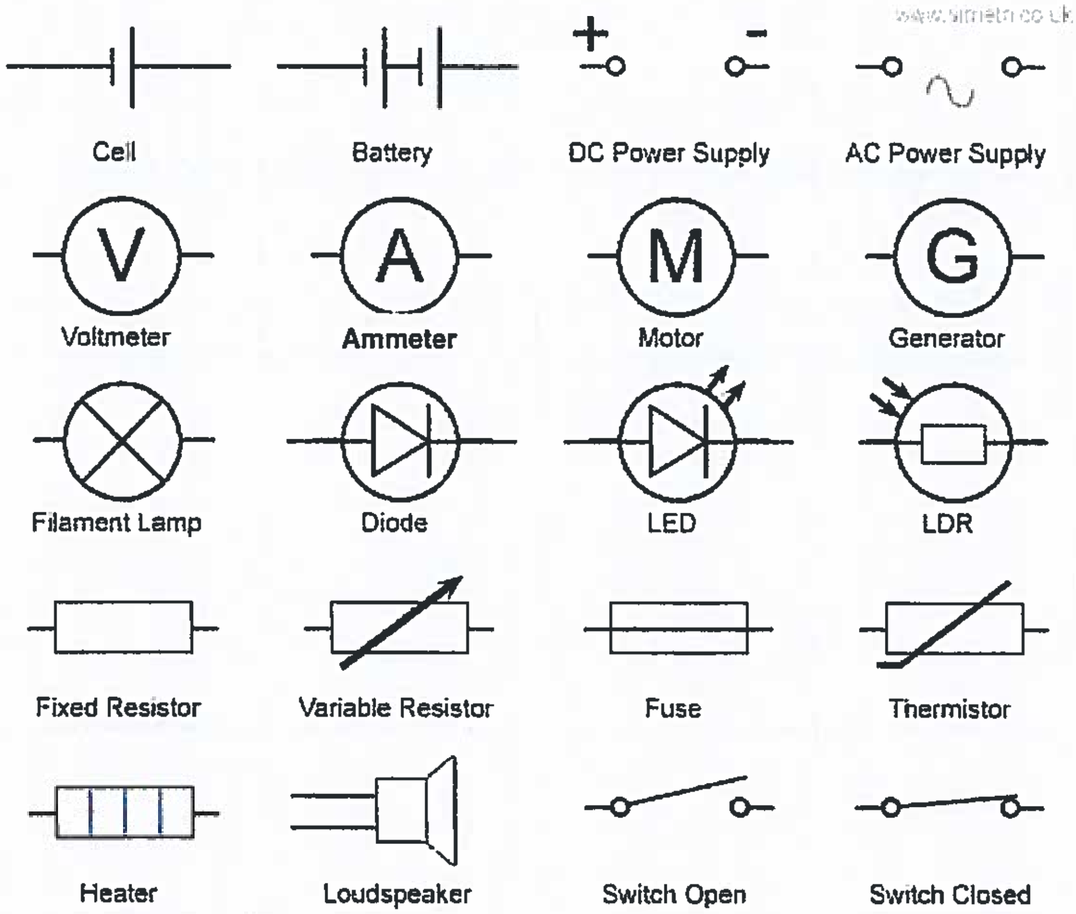
WJEC GCSE SCIENCE

Triple Award
Physics Topics
Year 10

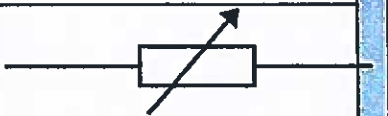
Revision Guide

Electrical Component Symbols



Unit 4 - Electricity

Simple electrical circuits.

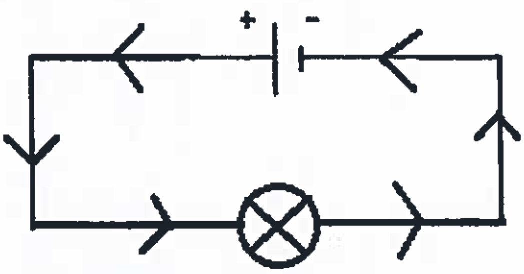
Device	Symbol	Device	Symbol
Wire		Cell / Battery	
Power Supply		Bulb	
Open switch (Off)		Closed switch (On)	
Diode		Resistor	
Variable resistor		Motor	

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)

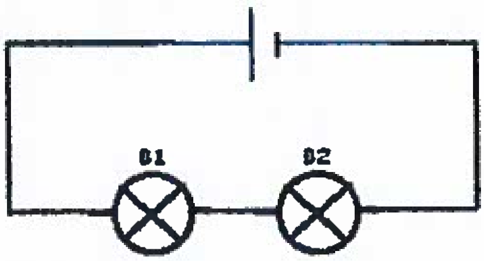
Resistance is a measure of how difficult it is for current to flow through a wire or device. More resistance means less current because it is more difficult for it to flow. Resistance is caused due to the collisions between the free electrons and the atoms/ions in the metal.

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

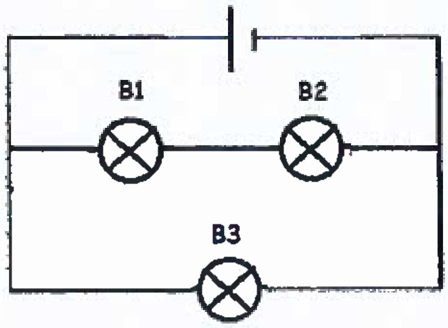
Name	Unit	Measured using	Symbol	Connected in...
Current	***Amps – A***	***Ammeter***		***Series***
Voltage	***Volts – V***	***Voltmeter***		***Parallel***
Resistance	***Ohms - Ω***			

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.

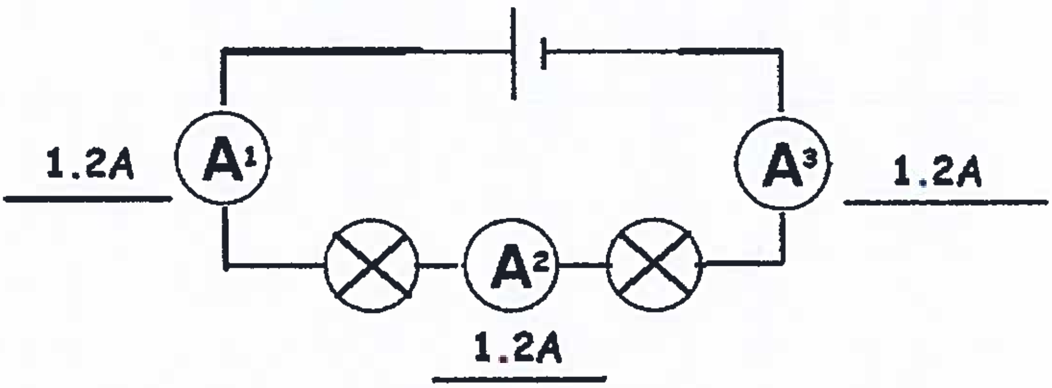


Parallel circuit: in a parallel circuit there is more than one path and the circuit is divided into branches. Bulbs B1 and B2 are in series but B3 is in parallel with them. If bulb B3 breaks then B1 and B2 will continue to work.



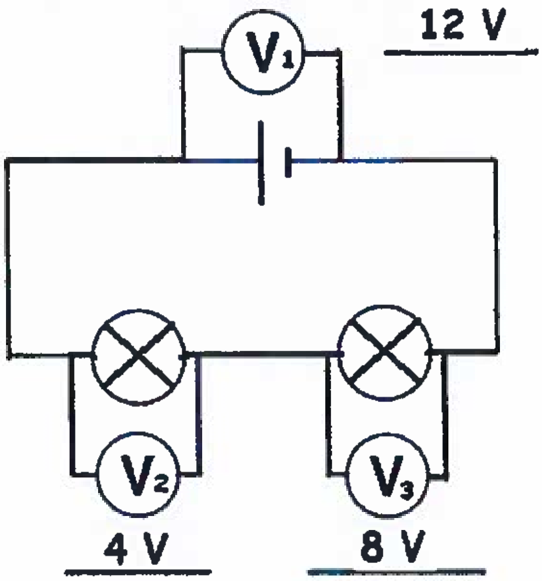
Measuring current and voltage in circuits.

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



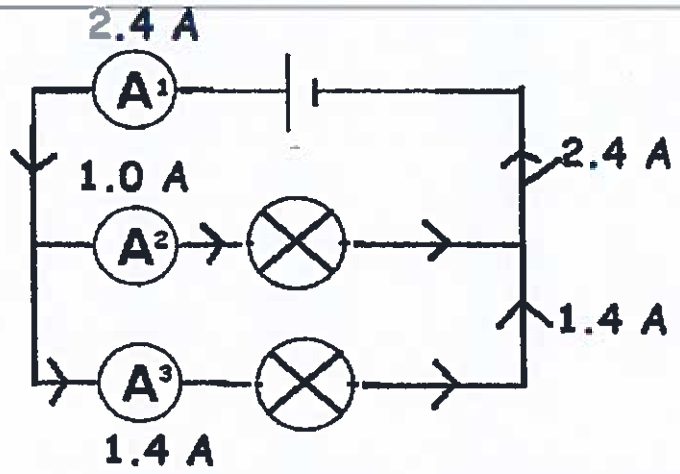
The value of the current is the same at all points ($A_1 = A_2 = A_3$) in the circuit since there is only one path for the current to flow.

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).

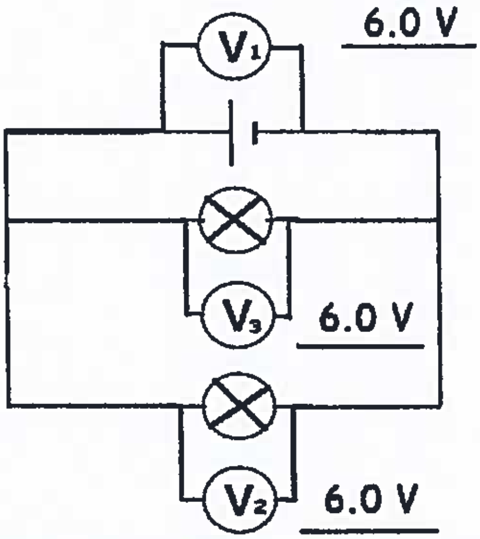
Current in parallel circuits: the ammeter in this series circuit is connected in series.



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).

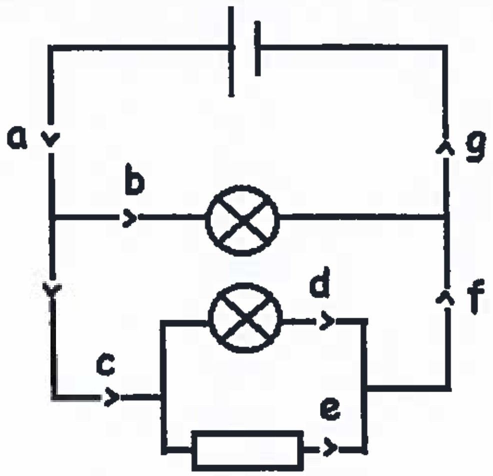
Voltage in parallel circuit: the voltage across all components in parallel is the same.

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.

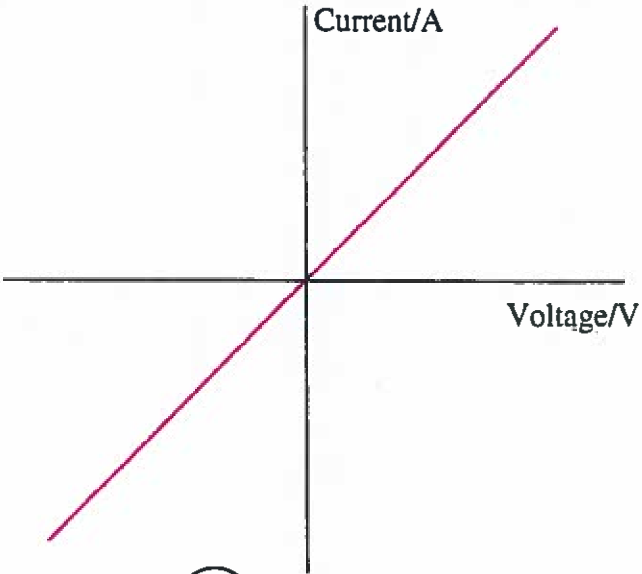


Point	Current (A)
a	3.6
b	2.0
c	
d	1.2
e	
f	
g	

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

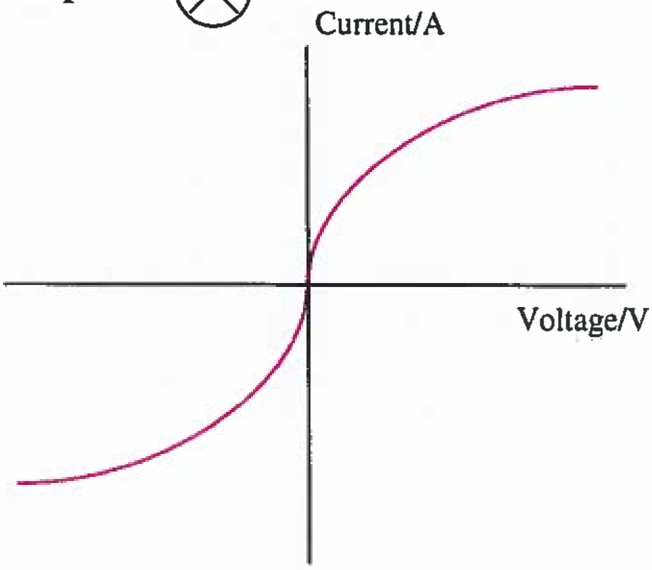
Voltage/Current (V/I) Graphs

Fixed Resistor (or wire) at constant temperature.



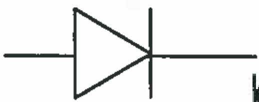
- Voltage is directly proportional to current.
- (As voltage increases, so does current.) The resistance is constant
- (R = V/I)
- The steeper the line, the lower the resistance of the resistor or wire.

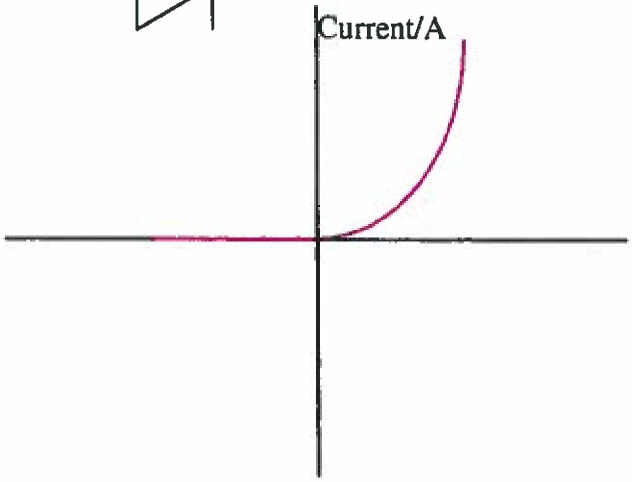
Filament Lamp



- Voltage is proportional to current.
- (As voltage increases, so does current.) The resistance is constant
- (R = V/I)
- The steeper the line, the lower the resistance.
- As the lamp gets brighter and hotter, it's resistance increases.

Diode



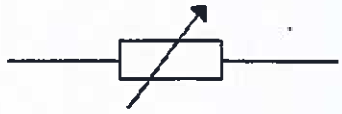


- A diode only allows current to flow in one direction.
- Reversing the voltage (potential difference means no current will flow.

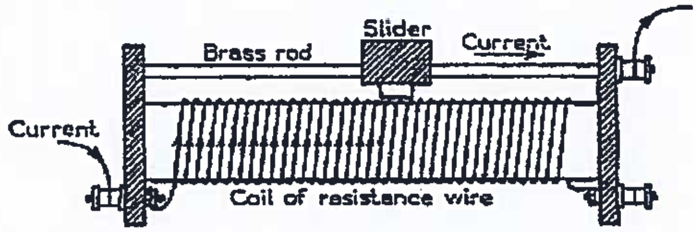
Variable resistors (controlling the current).

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.

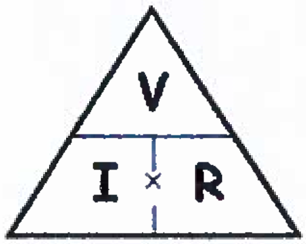


Wire-wound rheostat

Ohm's law

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

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



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

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

V = 1.8 x 15 = 27 V

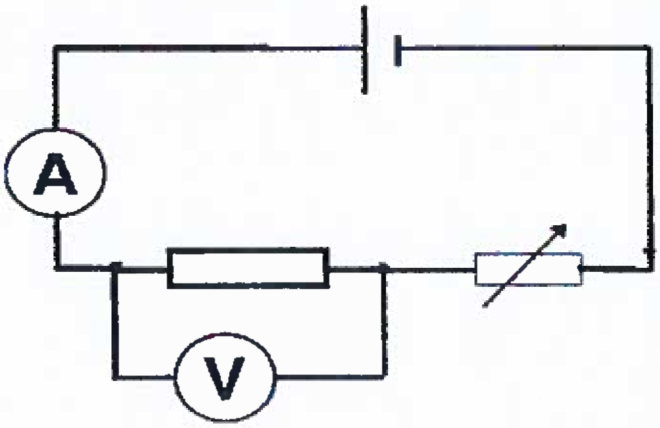
Q1. Calculate the current through a 2kΩ resistor when there is a voltage of 230V across it.

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.

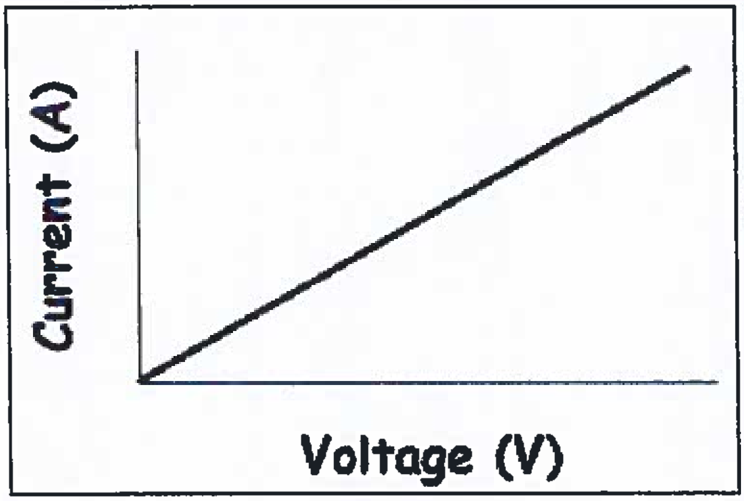
Answers: Q1 = 0.115 A , Q2 = 57.5 Ω

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***.

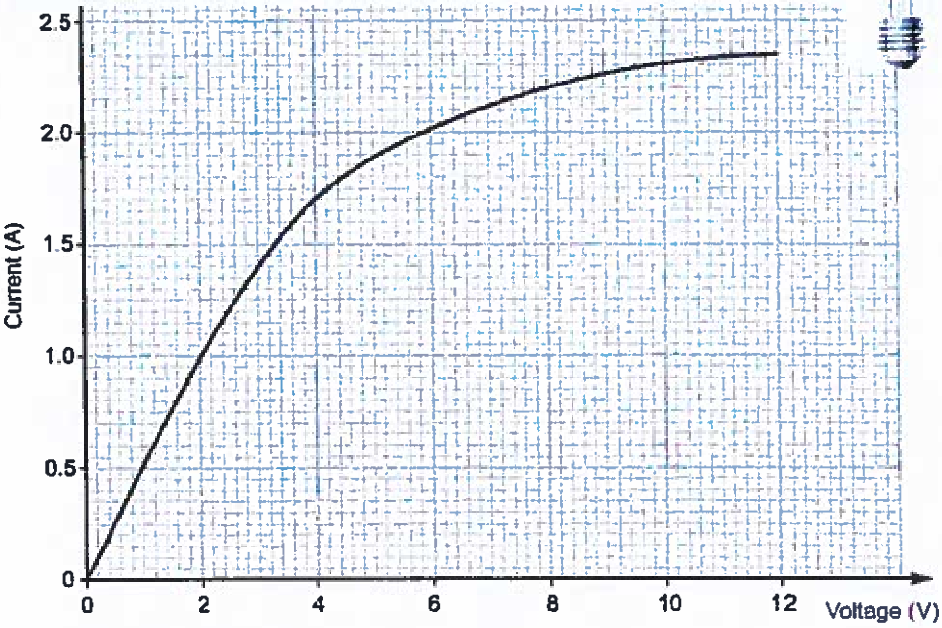
Changing resistance

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

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

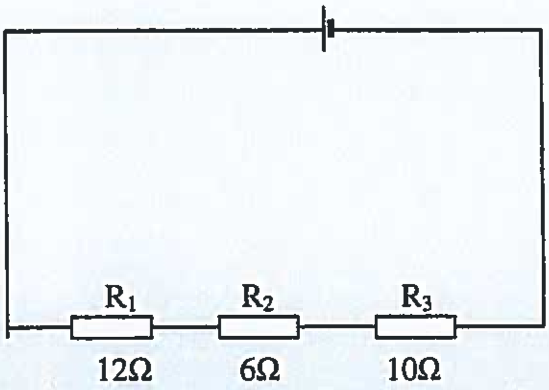
Total Resistance:

1. Series Circuits.

The total resistance in a series circuit is calculated by adding all the individual resistances

$$\mathbf{R_T = R_1 + R_2 + R_3 \ldots\ldots\ldots\ldots\ldots\ldots}$$

Example 1:



Remember – the components don't all have to be fixed resistors. There can be a mixture of resistors, lamps, motors, etc. As long as you know the resistance of each component, you can work out the total.

$R_T = R_1 + R_2 + R_3$

$R_T = 12\Omega + 6\Omega + 10\Omega$

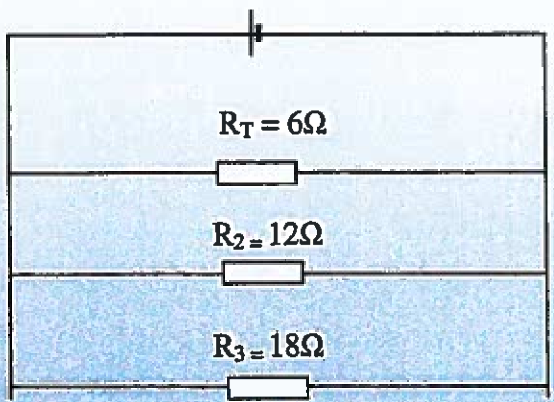
$= \underline{28\Omega}$

2. Parallel Circuits (Higher Tier Only)

The total resistance of a parallel circuit is *less* than the individual resistances of any of the components!

$$\mathbf{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots\ldots}$$

Example:



$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_T} = \frac{1}{6\Omega} + \frac{1}{12\Omega} + \frac{1}{18\Omega}$$

The lowest common multiple of 6. 12 and 18, is 18.

$$\frac{1}{R_T} = \frac{(3x1)}{(3x6\Omega)} + \frac{(2\,x1)}{(2x12\Omega)} + \frac{(1x1)}{(1x18\Omega)}$$

$$\frac{1}{R_T} = \frac{3}{18} + \frac{2}{18} + \frac{1}{18} = \frac{6}{18}$$

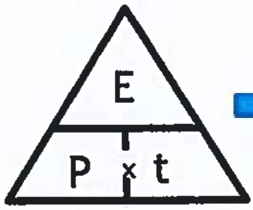
Now find the reciprocal of both sides

$\frac{R_T}{1} = \frac{18}{6}$ ***OR*** $\underline{R_T = 3\,\Omega}$

Power-equations

In general, power refers to how much energy is transferred per second. So, the equation for power is : Power = Energy ÷ time

$$P = \frac{E}{t}$$



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

$$E = P \times t$$

$$t = \frac{E}{P}$$

Energy is measured in Joules (J)
Time is measured in seconds (s)
Power is measure in Joules per seconds (J/s) or Watts (W)

Example

If the power of a kettle is 3000 W, and it's on for 3 minutes, how many Joules of energy has it converted ?

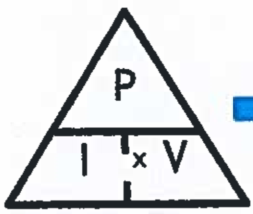
Answer : $E = P \times t = 3000 \times (3 \times 60) = 540\,000$ J

Look !!! The time must be in <u>seconds</u>, not minutes.

In electrical circuits, there's also another equation for power :

Power = current x voltage

$$P = I \times V$$



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

$$I = \frac{P}{V}$$

$$V = \frac{P}{I}$$

Current is measured in Amps (A)
Voltage is measured in Volts (V)

Example

If the power of a hair dryer is 1.2 kW, and it's working on "mains" power (voltage = 240 V) what's the current flowing ?

Answer : $I = P / V = 1200 / 240 = 5$ Amps (or 5 A)

Electrical Power:

Power is the rate of energy transfer - *learn this definition!*

$$\text{Power} = \frac{\text{Energy}}{\text{Time}} \quad \text{OR} \quad P = \frac{E}{t}$$

Power – *Watts (W)*; Energy – *Joules (J)*; Time – *seconds (s)*

Example:

*A filament lamp transfers **1000J** of electrical **energy** into light energy and thermal energy in a **time of 10s**. Calculate the input power of the lamp.*

$$Power = \frac{Energy}{time} \quad OR \quad P = \frac{E}{t}$$

$$Power = \frac{1000J}{10s} = 100W$$

Electrical Power: We can calculate the power rating of an electrical appliance if we know the potential difference (voltage) across it and the current through it.

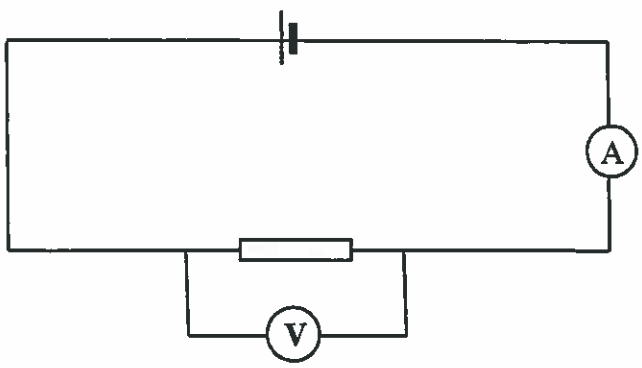
(Remember voltage and potential difference mean the same thing!)

Power = current x voltage *OR* $P = IV$

Power – *Watts (W)*; current – *Amps (A)*; voltage – *volts (V)*

Example:

The fixed resistor in the circuit shown transfers electrical energy to thermal (heat) energy. Calculate it's power if the voltmeter reads 12V and the ammeter reads 3A.



Power = current x voltage

Power = 3A x 12V

= <u>36W</u>

Electrical Power: - *Higher Tier Only*

A different way of calculating Power can be achieved by combining P = IV with V = IR *(Ohm's Law).*
This is used when we know current and the resistance of a component, but not potential difference (voltage).

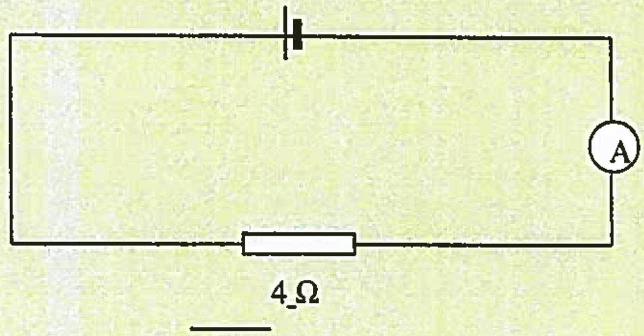
Power = current² x resistance **OR** $P = I^2R$

(*You* do not *need to know how to derive this equation*)

Example:

The fixed resistor in the circuit shown transfers electrical energy to thermal (heat) energy.

Calculate it's power if the ammeter reads 3A.



$P = I^2R$

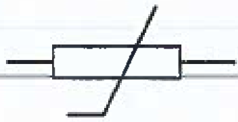
$P = 3^2 x\ 4$

$= \underline{36W}$

Task:

Look at the example on the previous page. **State** *(no calculation needed) the likely p.d. across the fixed resistor.*

Answer: 12V. *The power of the resistor and the current are the same in both examples.*
Therefore, the p.d. should be the same. Although it's not needed in this task, Ohm's Law
V = IR, can be used to prove this.

Resistance of thermistors: 

Beaker of water at 100°C

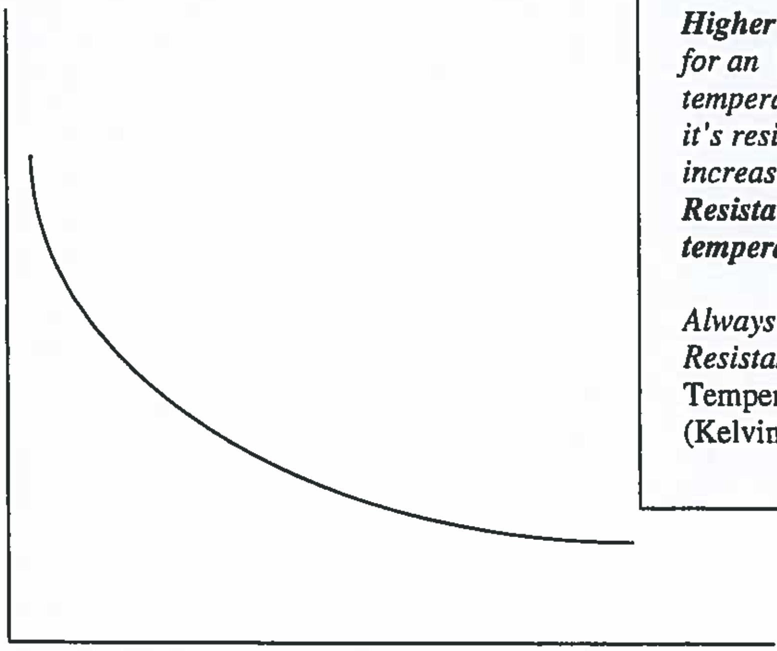
Thermistor

Multimeter set to measure resistance (ohmmeter)

Method: *Connect the thermistor to the ohmmeter, then place the thermistor in a beaker of water at 100°C (boiling). Measure the temperature of the water using a thermometer or data logger (not shown). Record the water temperature and resistance of the thermistor at 100°, 90°, 80°, etc, until the temperature stops falling (room temperature).*

Results:

Resistance/Ω

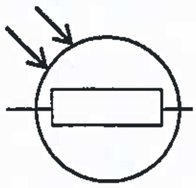


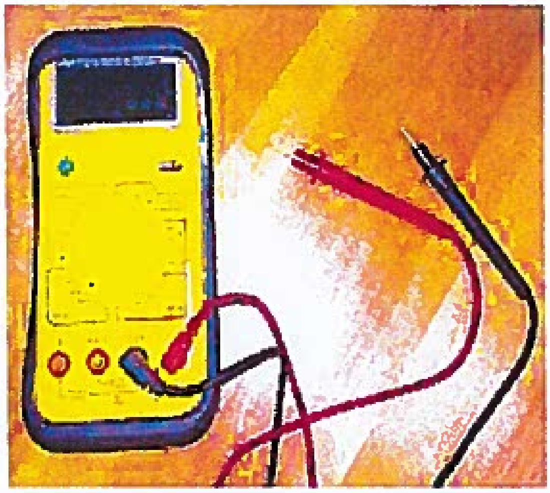
Temperature/°C

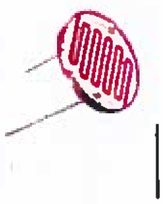
Higher Tier: *This graph shows results for an* ntc *thermistor (negative temperature coefficient). This means that it's resistance falls as the temperature increases.*
Resistance is inversely proportional to temperature.

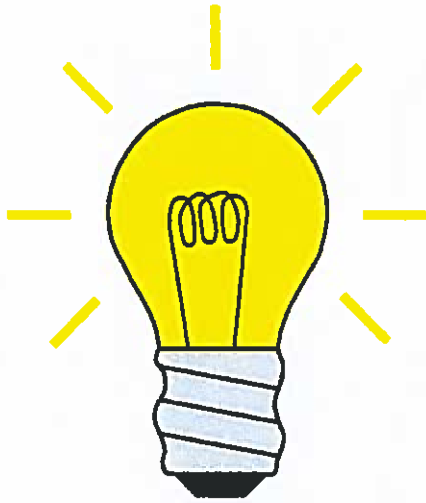
Always check the units on the axis.
Resistance may be in Ω, k Ω, M Ω, etc.
Temperature may be in °C or, K (Kelvin).

Resistance of Light Dependant Resistors (LDR's):







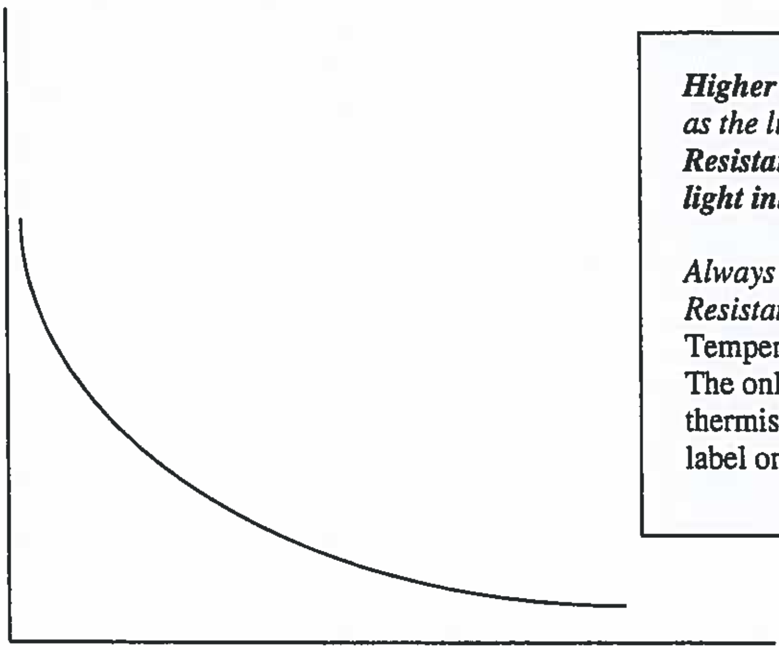


Multimeter set to measure resistance (ohmmeter)   LDR   Light source (variable brightness/intensity)

Method: *Connect the light dependant resistor (LDR) to the ohmmeter. The LDR must be shielded so that only light from the light source can hit it. Shine the light on the LDR and measure its resistance. Use a variable resistor to change the brightness of the bulb. Continue to measure light intensity.*

Results:

Resistance/Ω



Light intensity (or brightness)

> ***Higher Tier:*** *The LDR's resistance falls as the light intensity increases.* ***Resistance is inversely proportional to light intensity.***
>
> *Always check the units on the axis. Resistance may be in* Ω, k Ω, M Ω, etc. Temperature may not be given a unit. The only way to tell a graph for a thermistor and LDR apart is to check the label on the *x* axis.

Comparing the different power stations

All power stations need an energy **resource**, i.e. a source of energy that can be converted to electrical energy. All these resources are classed as either **renewable** or **non-renewable**.

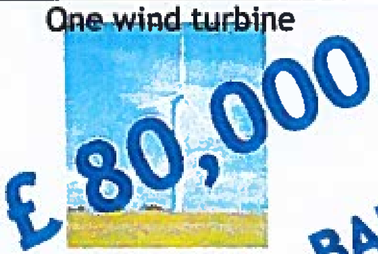
A renewable resource is a resource we can make more of it in a short amount of time e.g. biomass, or is produced continually e.g. wind or rain (hydroelectricity).

Renewable	Non-renewable
Geothermal	Coal
Solar	Oil
Wind	Gas
Waves	Nuclear
Tidal	
Hydroelectric	
Biomass	

These are fossil fuels. When they are burned to produce heat, they also produce Carbon Dioxide (CO_2). CO_2 is a greenhouse gas that causes global warming.

Costs

One wind turbine



BARGAIN ??

Wylfa Nuclear power station

At first glance it may look like wind power is a much cheaper option, however, to make a fair comparison, we must quote these **commissioning** (build) cost values **per MW (Mega Watt)** of electricity produced :

Wind farm : Each wind turbine costs £80 000, and produces about 25,000 Watts.
Number of wind turbine needed to make 1 MW = 1,000,000 W ÷ 25,000 W = 40
Total cost = 40 x £80,000 = **£3.2 million per MW**

Nuclear : Total commissioning cost is £2,000 million (£2 billion). Total electrical power produced is about 650 MW.
Therefore, Cost per MW = £2,000 ÷ 650 = **£3.1 million per MW**

So, in fact, the build costs are almost identical ! However, it's not quite this simple . . .
Other costs to consider are : Day-to-day **Running costs, Decommissioning costs** (the safe dismantling of the power station when it becomes too old).

Comparing the different power stations

In the Physics exam., you may be given data, usually in a table, and you will have to compare different power generation systems. This may involve some calculations like the examples on the bottom of the previous page.

Although you are not expected to know all the details for all the different power stations etc., it may be wise to know some basic advantages and disadvantages for some of the most commonly used ones - here's an example :

Type	Build cost	Running costs (inc. fuel)	Decomm. costs	Environmental	Socio-economic
Nuclear	High	Medium	Very high	No CO_2, but radioactive waste produced	Creates many jobs for decades. Risk with terrorism ?
Coal	Low	Medium	Medium	CO_2 produced	Creates many jobs for decades
Wind	High	Very low	Low	Eye-sore ?	Few jobs created long term
Hydro	High	Very low	Medium	Can affect wildlife + irrigation if dam placed in rivers	Creates many jobs for decades

Note : A big debate at the moment is that the decommissioning cost (demolition etc.) for a nuclear power station is much more than originally estimated. Much of this is because the radioactive sections of the reactors stay dangerously radioactive for decades. Some estimates put the decommissioning cost at around £50 billion ! When this is accounted for in the overall costs of a nuclear power station, the price of the electricity is higher than it seems at present.

Non-renewable Energy Sources:

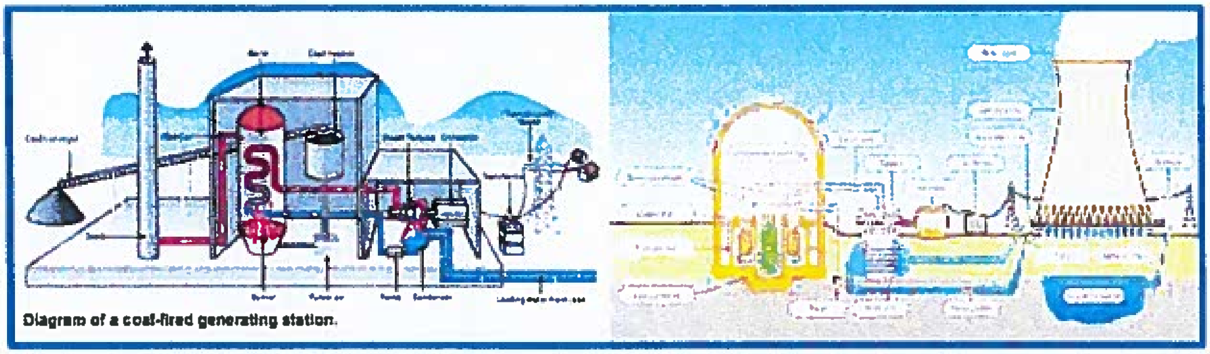


Diagram of a coal-fired generating station.

1. **Fossil Fuel Power Stations** use either coal, oil or, natural gas as an energy source.
2. They all use ***combustion*** to transfer the ***chemical energy*** in the fuel into ***thermal energy***.
3. This is used to boil water.
4. The steam that this produces has ***kinetic*** energy which is used to turn a turbine and generator.
5. The generator transfers the ***kinetic energy*** into ***electrical energy***.

1. **Nuclear Power Stations** use nuclear fuel (***uranium*** or, ***plutonium***) as an energy source.
2. They use ***nuclear reactions*** to transfer ***nuclear energy*** to ***thermal energy***.

Stages 3, 4 and 5 are exactly the same as in a fossil fuel power station.

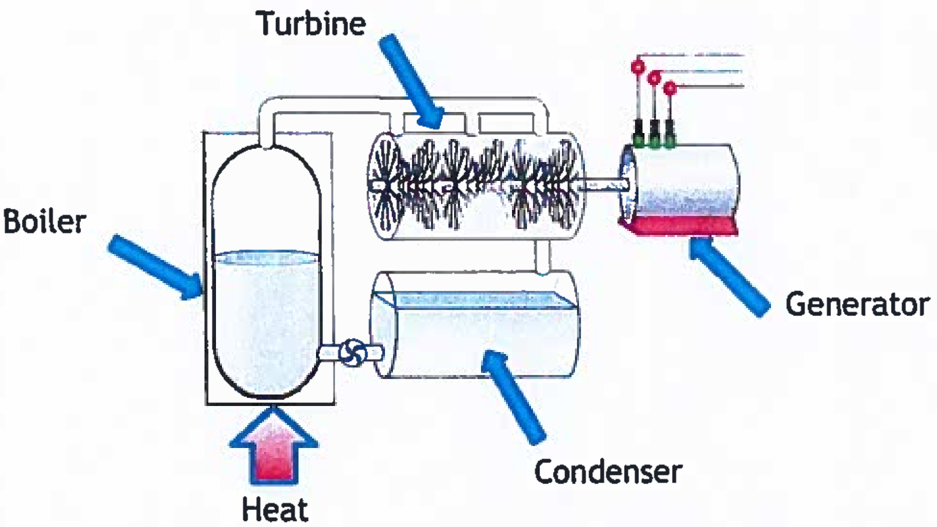
	Fossil Fuel Power Stations	Nuclear Fuel Stations
Produce CO_2 (greenhouse gas).	✓	✗
Causes acid rain (sulphur dioxide, SO_2).	✓	✗
Causes ill health due to atmospheric pollution (e.g. NO_x).	✓	✗
Highly radioactive waste that is dangerous for over 100 000 years.	✗	✓
Can produce massive amounts of electrical energy.	✓	✓
Electricity produced is relatively cheap.	✓	✓
Can be turned on and off quickly.	✗	✗
Energy source will run out.	✓	✓

Connah's Quay Power Station and bridge

Producing electrical energy

There are 3 main ways to produce electricity for use in the national grid.

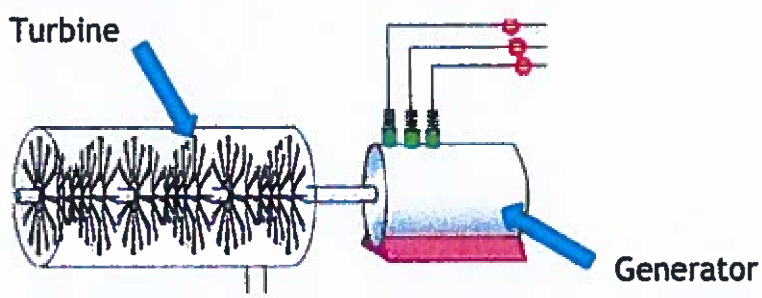
1. Shown below is a typical set-up for most power stations. The fuel is used to provide heat energy to water in a boiler. The water changes to steam which turns the blades of a turbine. The turbine is connected to a generator which then produces electricity.



Coal, oil & gas power stations work like this by burning the fuel.

Note that a nuclear power station also works as shown in the diagram, but that nuclear fuel doesn't "burn" in the usual way, and so doesn't release CO_2.

2. Shown below is a typical set-up for most other types of 'generators', e.g. hydroelectric ; tidal ; wave ; wind.
Water or air strikes the blades of a turbine to make it turn.
The turbine is connected to a generator which then produces electricity.



3. PV (photovoltaic) solar cells convert light energy directly to electrical energy.

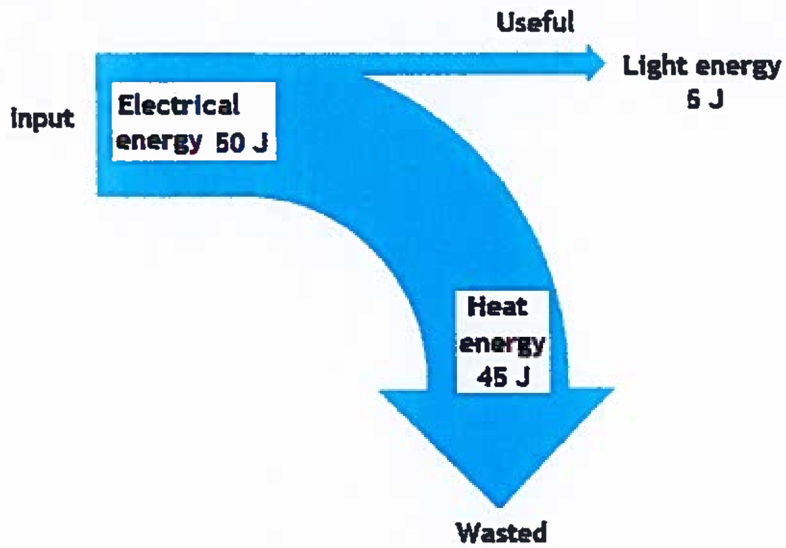
Energy Transfer

Type of energy	Example
Electrical	Into hairdryer.
Heat	Cooker.
Kinetic	Moving energy - car.
Sound energy	Speaker
Light energy	An object which emits light - LCD screen.
Chemical energy	Stored in food/battery.
Gravitational potential energy	Increases with height above ground - pump storage station.
Elastic potential energy	Stored in stretched elastic band/spring.

Example: energy transfer

Sankey Diagrams

Energy transfers can be shown using **Sankey** diagrams. They show the energy types which are involved and also the amount of energy involved. Below is a Sankey diagram for a filament bulb.



Key points

- Energy input = Energy output: 50 J (input) = 45J + 5 J (output)
- Useful energy is straight on.
- Wasted energy is curved downwards/upwards.
- Width of arrow tells us the amount of energy (to scale)
- Width of arrow is proportional to the amount of energy. They are drawn to scale e.g. 10J = 5mm

Efficiency

Energy efficiency: this is a measure of how much useful energy comes out of a device. It is measured in %.

$$\%\ \text{Efficiency} = \frac{\underline{\text{USEFUL energy out (or power) tranfer}}}{\text{TOTAL energy (or power) input}} \times 100$$

Example: using the data from the Sankey diagram.

$$\%\ \text{Efficiency} = \frac{5}{50} \times 100 = 10\%$$

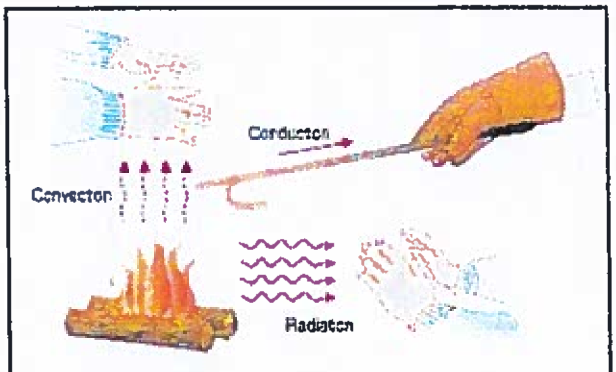
This is very poor and shows that the bulb is not very efficient. You cannot get more than 100%!!!

Coal power station 35% efficient, LED lights are 90% efficient and car engine 40% efficient.

The more efficient a power station is the ***less energy*** that is needed to be burnt so the ***less carbon dioxide*** emitted and also fossil fuels last longer.

Thermal energy (heat) transfer.

Thermal energy moves from **HOT** (High temperature) to **COLD** (lower temperature) (down a temperature gradient) e.g. a hot cup of tea gives out thermal energy to the surroundings.



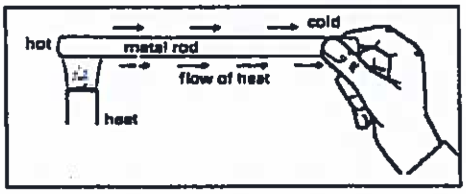
www.beodom.com

The greater the ***difference in temperature*** the more thermal energy transferred per second e.g. so the temperature of your mug of tea will drop at a greater rate when it is very hot.

3 types of thermal transfer: Thermal energy can be transferred via conduction, convection and radiation.

Conduction: In conduction the thermal energy flows through the object itself. It takes place in solids and liquids.

Conductors: materials which are good at conducting thermal energy e.g. metals like copper.



Insulators: materials which are poor at conducting e.g. air, plastic. Many materials which are insulators like wool trap air e.g. jumper.

Convection: Heat flows by convection in **liquids** and **gases** only. Convection cannot occur in solids because the particles are fixed.

This applies to liquids and gases:

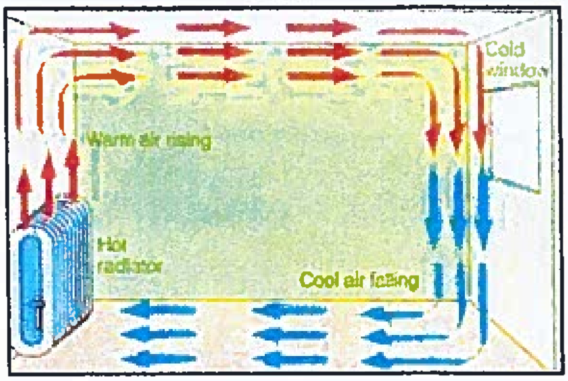
1. When gas/liquid heated.

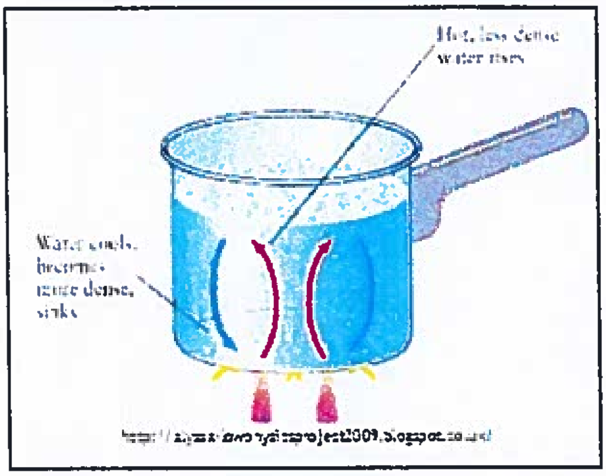
2. The particles speed up

3. Volume of gas/liquid increases. Gas/liquid expands.

4. Density decreases and so gas/liquid rises.

5. Colder, denser gas/liquid falls.





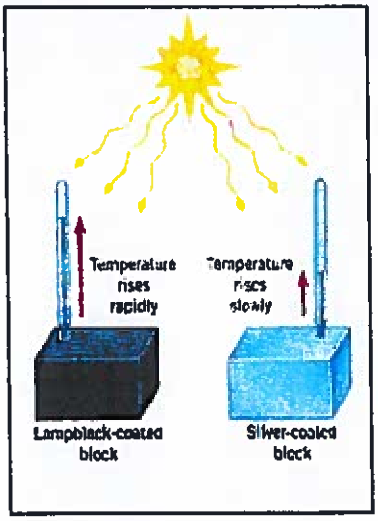
Some materials like foam trap air, which reduces the convection current. This reduces heat loss/transfer through convection.

Thermal Radiation (infrared). Any hot object will emit thermal radiation in the form of infrared electromagnetic radiation.

The higher the temperature of an object the more thermal radiation it will emit. This is the only means of heat transfer through a vacuum (space). Objects can ***emit*** and ***absorb*** heat radiation

Shiny objects are good at reflecting thermal radiation e.g. aluminium foil around food, caravans painted white.

Matt black objects are very good at absorbing/emitting thermal radiation e.g. wood burning stove is painted black and black cars become hotter in the sun.

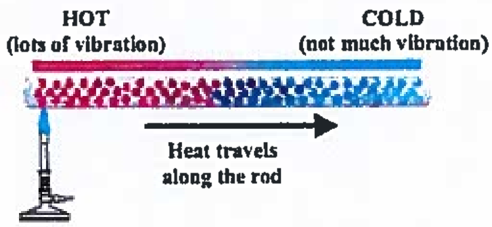


Dull Black	Shiny Black	Colours (dark --> Light)	White	Silver
Best Emitter/ Absorber	→	→	→	Poorest Emitter/ Absorber

A better understanding of Conduction and Convection !

Conduction

The atoms (or molecules) in a solid are close together and so, because they constantly collide with each other, they transfer heat energy quite quickly by conduction.



The atoms in gases are much further apart, and so collide less often. This is why conduction is very slow in gases.

Metals conduct heat very quickly making them better conductors, because they have **free electrons** which can move around within the metal, and therefore can carry the heat energy much more rapidly from one place to another.

Convection

When liquids or gases are heated the atoms or molecules that are heated up move more rapidly. These atoms then collide at higher speed and more often with other atoms around them.

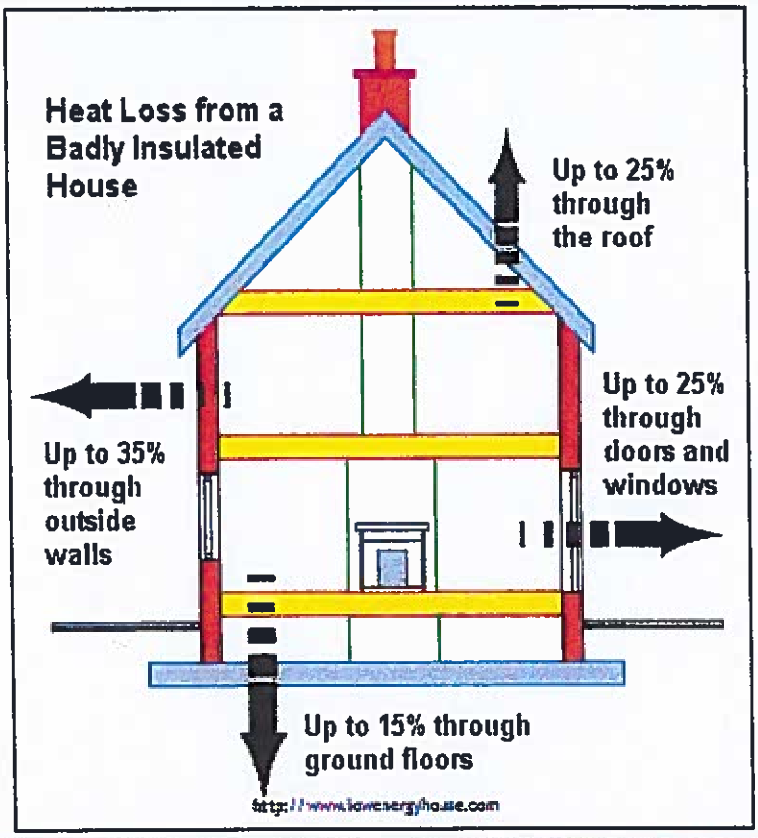
This leads to a short-lived, **localized** increase in pressure, and so this part of the fluid expands. (It's very similar to the section where V/T = constant, i.e. gases expanding at constant pressure).

The fluid in this locality is now less dense than surrounding fluid, and so it rises, forming a **convection current**.

Insulating the house

It is important to try and reduce the thermal energy loss from a house. This will reduce ***energy bills*** (saving money) and also reduce the ***carbon dioxide emissions*** as the result of heating your home. CO_2 is a greenhouse gas which increases global warming.

There are many types/systems of insulation that can be installed in the house to reduce **NOT stop** heat loss. Most of these insulating materials work because they ***trap air*** which is a poor conductor. If the air is trapped heat loss through convection is reduced because warm air cannot rise and cold air cannot fall.



Insulating systems

Insulation type/system	How it works.
Double glazing	Two sheets of glass separated by a gap filled with e.g. argon or a partial vacuum. It reduces heat loss through conduction and convection.
Draught proofing	Strips of draught proofing can be fitted around doors and window frames. Draught excluders can be placed at the bottom of doors. It reduces heat loss through convection.
Loft insulation	Rock wool (mineral wool) can be placed between the rafters in the loft. These materials are good at trapping air. Reduces the heat loss through conduction and convection.
Floor insulation	Fibreboard or mineral wool is placed to reduce heat loss via conduction and convection.
Cavity walls	Walls are built with an inner and outer wall. The gap/cavity can be filled with foam or insulation board which reduces conduction and convection.

Installing wind turbines and solar planes DO NOT reduce heat loss

Note: The higher the temperature of the inside of your house compared to the outside the more energy your house will lose per second because of a greater difference in temperature.

Comparing the costs

There are 2 main energy requirements in the home :

1. Electricity

2. Heat

You will be expected to compare the different energy sources in terms of their cost, their effect on the environment, **payback time**, etc.

"Payback time" is the time it takes to get the money back in energy savings for the money spent on a particular improvement. Here's the equation for calculating "payback time" :

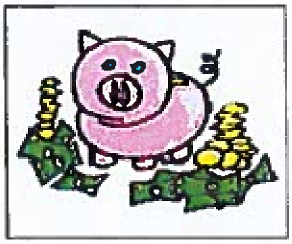
Payback time = cost ÷ savings per year
(in years)

Note : This equation is not given in the exam at all, so you'll have to memorise it !!

So, payback time can be calculated by dividing the cost of the system with the saving per year (how much your bill has been reduced).

Example: it costs £4000 to install double glazing in your house. Your energy bills are reduced by £175 per year. How long will it take before the cost of your investment is paid back.

$$\text{Payback time} = \frac{4000}{175} = 22.9 \text{ years.}$$



You will not be expected to remember data about different energy sources, only use what is given in the exam question.

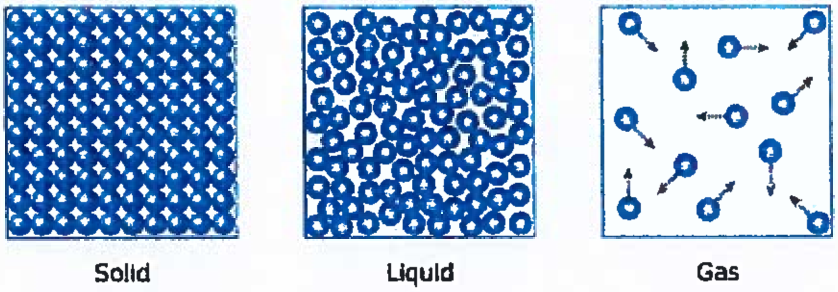
See the example on the next page.

Density

Density tells us how much mass of a certain material is contained within a certain volume.

The more material in a given volume, the greater the density.

So, in general, solids have high density values whereas gases have very low values:

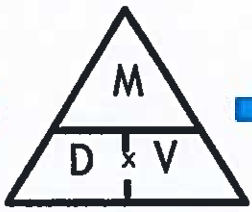


Here's the equation for calculating density :

$$\textbf{Density} = \frac{\textbf{Mass}}{\textbf{Volume}}$$

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

$$D = \frac{M}{V}$$



$$V = \frac{M}{D}$$

$$M = D \times V$$

Example

Calcuate the density of a glass block, length = 14cm, width = 4.5cm, height = 2cm, whose mass = 315g.

Volume of the block = $l \times w \times h$ = *14 x 4.5 x 2 = 126 cm³*.

So, density of block, D $= \frac{M}{V} = \frac{315}{126} =$ **2.5 g/cm³**

Water has a density of exactly 1 g/cm³ (or 1000 kg/m³).
Air has a density of about 0.0013 g/cm³.

This is why a turbine driven by a certain volume of water is capable of generating more electricity than a turbine driven by the same volume of air.
1 m³ of water weighs about 854 times the same amount of air.

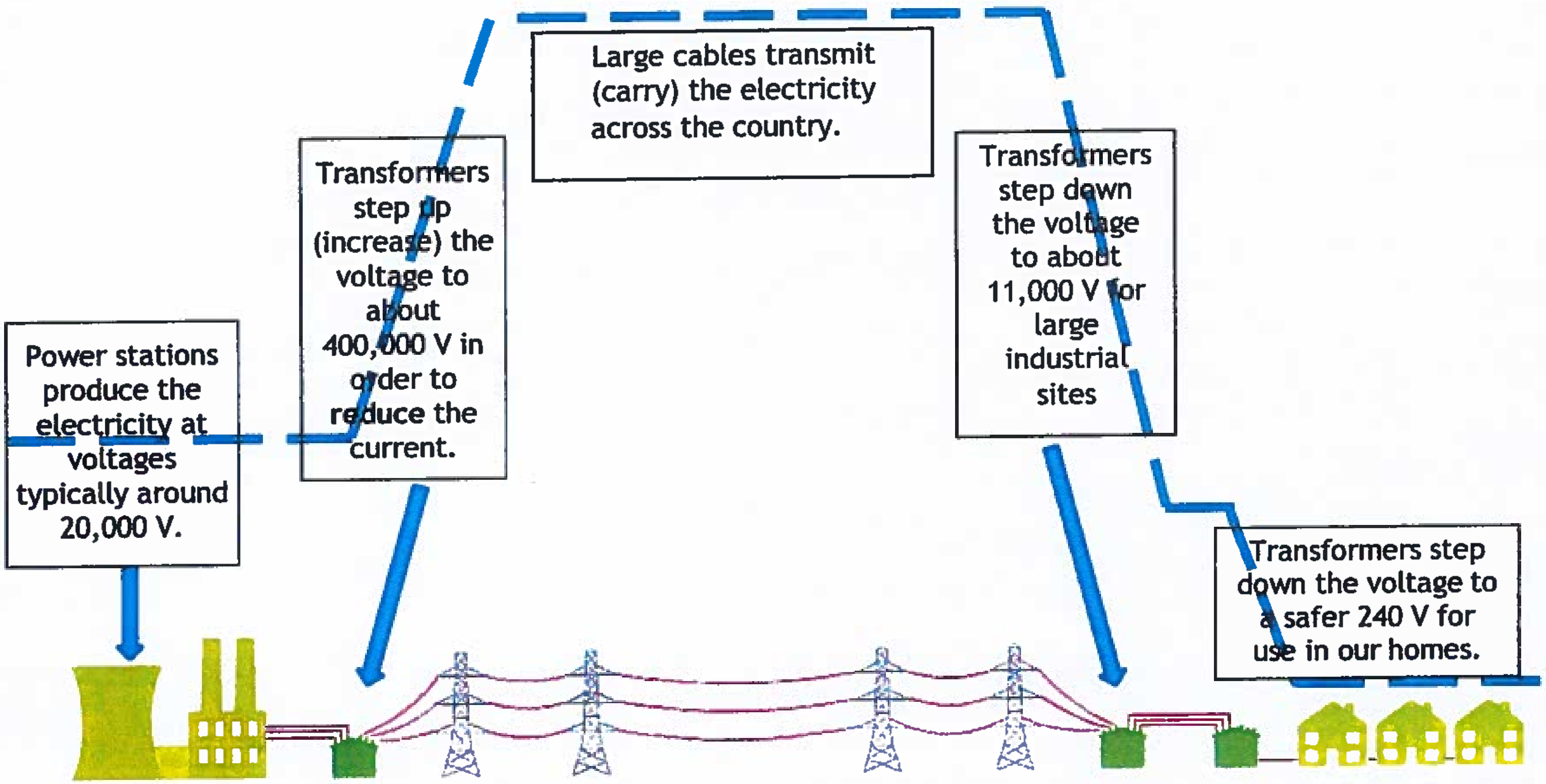
Unit 1 - The National Grid

Overview

The National Grid is the system of power stations, cables (& pylons), and transformers that supply electrical energy to our homes, schools, industries etc.

The main benefit of getting our electrical energy from a "grid" like this is that it is very reliable.

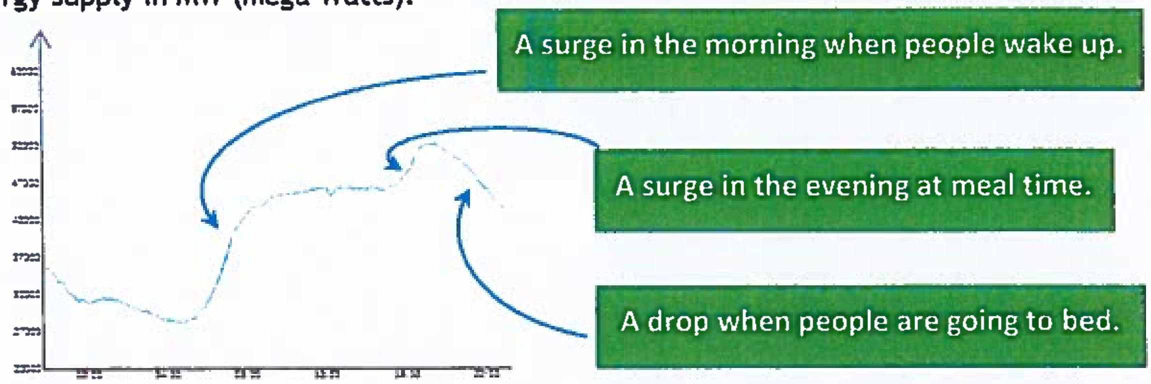
The only other option to produce electricity is <u>micro-generation</u> (e.g. solar panels on the roof; small wind turbines in the garden, etc.)



2. Electricity can't be stored on a large scale

Since it is not practical to store electrical energy on a large scale, the right amount of it must be produced every second of every day. This causes a big headache for the national grid, as it has to try to get the right balance between <u>supply</u> (how much is produced) and the <u>demand</u> (how much is needed).

Energy supply in MW (Mega Watts).

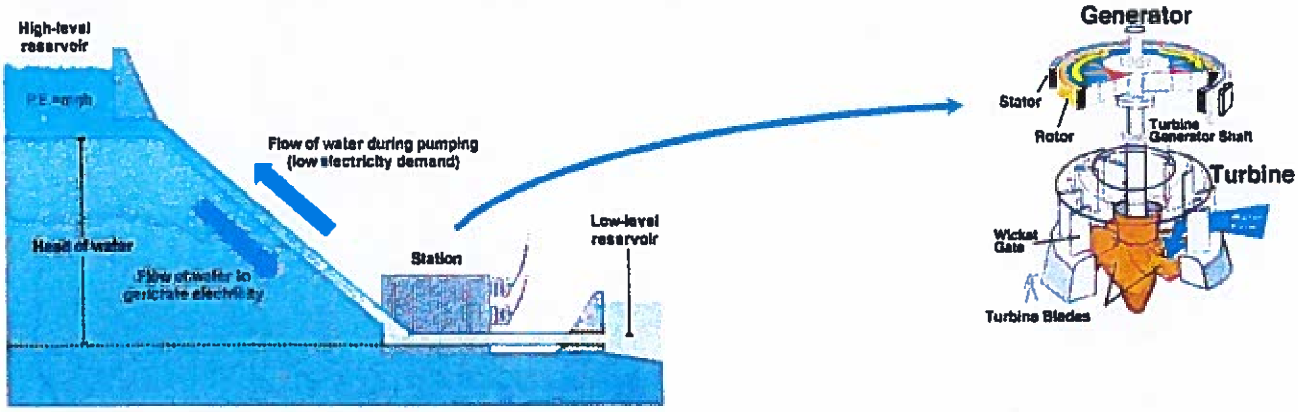


Note that "one-off" special events can cause surges too, as well as day-to-day events, e.g. a popular event at the Olympics; the FA cup final etc. The National Grid try to predict when these occur by looking at the TV listings !

A surge in demand can cause a black-out (no electricity across a large part of the country) unless the National Grid respond very quickly. More electricity is produced within seconds by fast-response power stations like "Electric mountain" in Llanberis, N.Wales - a hydroelectric power station.

When needed they open a few valves, which allow water in the upper lake to flow down through turbines.

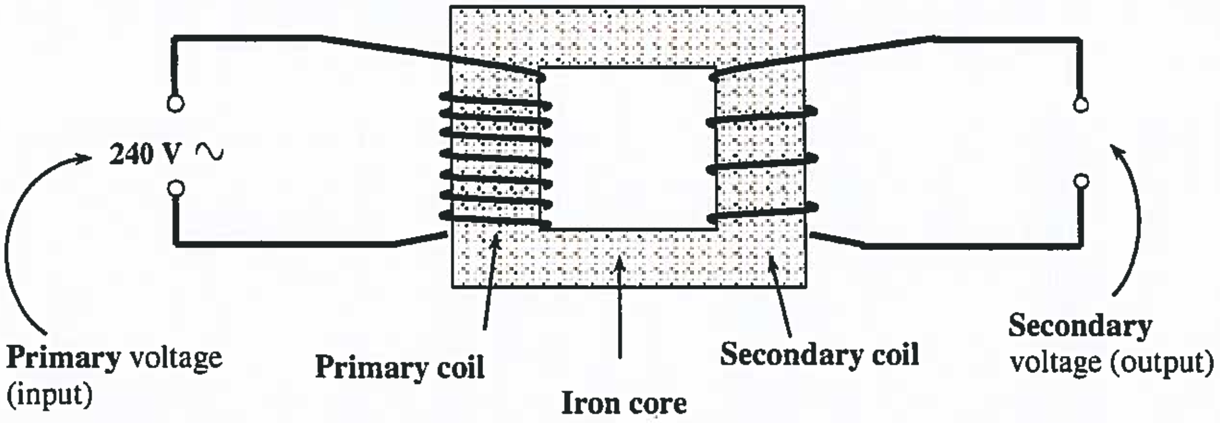
A fast-response hydroelectric power station (pump-storage)



Using Induction – TRANSFORMERS

A transformer is a device that makes use of the fact that electricity can be created (induced) by a <u>changing magnetic field</u>. Transformers are used to increase (step-up) or decrease (step-down) the voltage.

Here's a diagram of a transformer where two separate coils have been wound around two sides of the same piece of solid iron 'core':



← Here's a large transformer in the National grid ......

...... and here's a small transformer - a phone charger →

The explanation for how electricity is created in the secondary coil could be asked for in a "QWC"-style examination question. Here's an example of a well-structured answer :

The alternating current in the primary coil creates a changing magnetic field around it. Iron is a magnetic material, and so easily transmits this magnetic field to the secondary coil. The constantly changing magnetic field around the secondary coil induces a voltage in this coil.

Additionally, whether this output voltage is greater or lesser than the primary voltage depends on the amount of turns in the secondary coil as compared to the primary.

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

where
V_1 = voltage across the primary coil
V_2 = voltage across the secondary coil
N_1 = number of turns on the primary coil
N_2 = number of turns on the secondary coil

Example : *The input (primary) voltage of a phone charger is 240V (mains). The output needs to be 4.8 V. Calculate "N_2" (the number of turns on the secondary coil) if N_1 = 2000.*

$$N_2 = \frac{N_1 \times V_2}{V_1} = \frac{2000 \times 4.8}{240} = 40 \text{ turns}$$

Which Energy Source?

You will need to use information you are given in the exam to decide which energy source is best. The information below gives a bit of background on ***some*** of the energy sources used.

Transport:

Diesel: Buses, trains, trucks and many cars use ***diesel*** fuel. It is usually cheaper and diesel vehicles often have better fuel consumption (they travel further on each litre of diesel). This means that it may produce less CO_2.

But, diesel vehicles produce tiny particles of carbon. These can be breathed in and can cause lung disease.

Petrol: Many cars use ***petrol.*** Petrol engines are quieter than diesel, but petrol is slightly more expensive.

Liquid Petroleum Gas (LPG): More and more cars and vans use lpg. It is much cheaper than petrol or diesel and produces less CO_2 and other atmospheric pollutants.

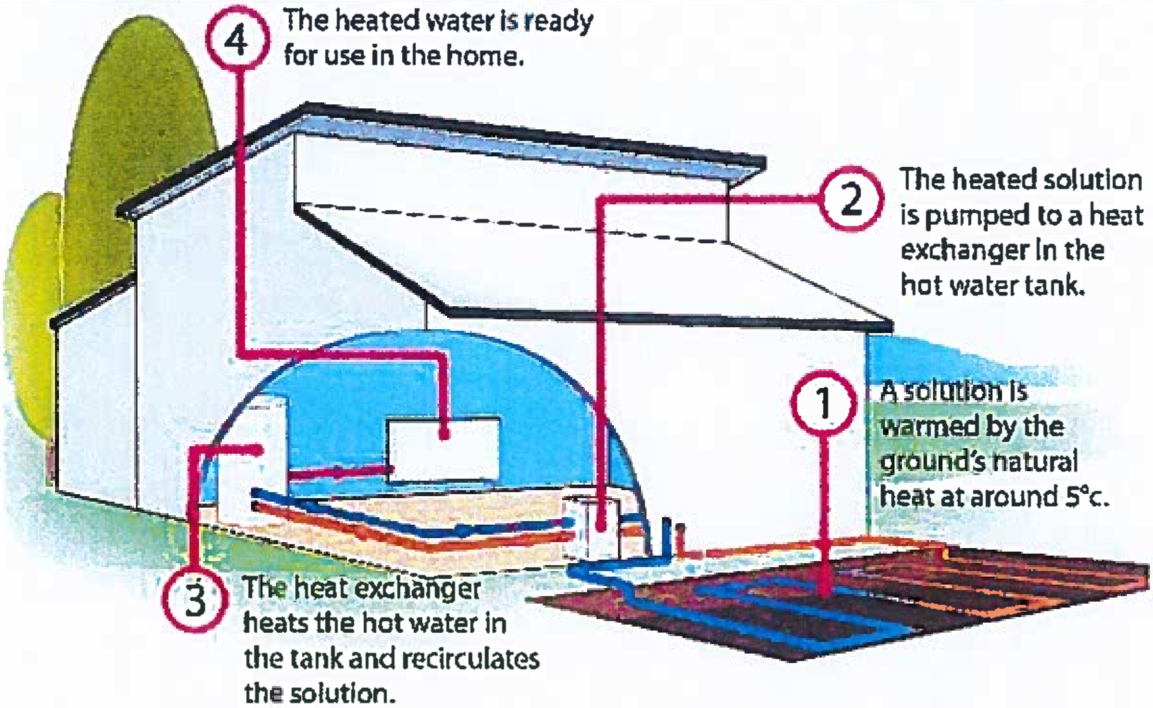
Electricity: Battery powered cars use electric motors. The cost of the energy can vary lots. Electric cars don't produce any atmospheric pollution themselves, so they are good to use in towns and cities where there may be a local pollution problem. But, if the energy they use comes from fossil fuel power stations, they still cause pollution.

Heating:

Fossil Fuels: Houses can be heated by burning coal, oil or natural gas (usually known as lpg or propane). Fossil fuels are good energy sources because, they contain a lot of energy which can be released quickly. They are bad energy sources because, they all produce CO_2 plus other atmospheric pollution.

Solar Energy: Houses can either use ***solar panels*** (which use heat energy from the sun to heat up water), or, ***photo-voltaic (p.v.) panels*** (which turn light energy into electrical energy). The energy is free, but the panels can cost quite a lot to install.

Ground Source Heat Pumps:



Calculating the cost of electricity

When electricity companies need to calculate your electricity bill, they simply count how many "units" (kWh) of electrical energy you've used since your last bill. Here's the equation for calculating "energy" :

Since $P = \frac{E}{t}$, re-arranging → $E = P \times t$ (see page 5 !!)

Normally, the units used are : J W s (Joules, Watts, and seconds)

However, the Joule is much too small for the electricity companies, so they use slightly different units :

E	=	P	x	t
(kWh)		kiloWatts		hours

The **number of units** of electrical energy used are therefore measured in **"kilo-Watt-hours"**

Once the "number of units" (kWh) has been calculated, it is then easy to calculate the cost of the electricity - see the example below :

Example

If the power of a microwave oven is 850 Watts, and is on for a total of 30 minutes, calculate the cost of the electricity it uses if each unit (kWh) costs 12 pence.

W → kW: ÷ 1000

minutes → hours: ÷ 60

Units used = P (kW) x t (h) = 0.85 x 0.5 = 0.425 kWh

Cost = 0.425 x 12 pence = 5.1 pence

What does it cost?

It costs money to use any electrical appliance – we have to pay for the energy it uses.

Information about how much it costs can be found form;

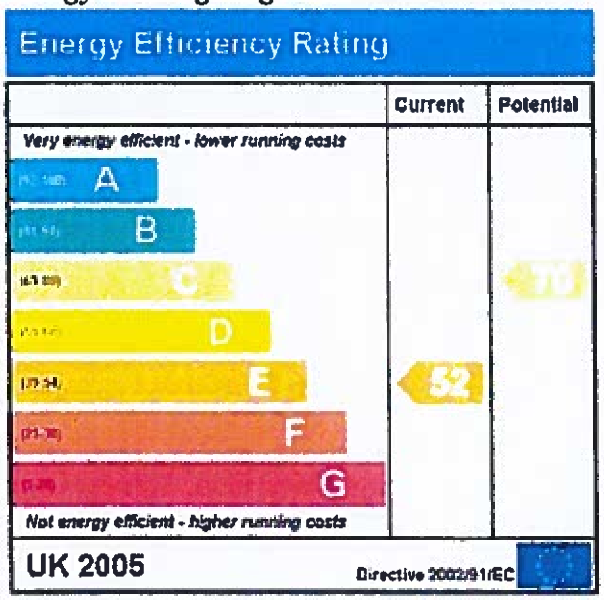
1. ***Measuring voltage and current.*** Then we can use the equations

   Power = Current x Voltage   and   Cost = Power x time x cost per kiloWatthour
   (remember, power is in kW and time in hours)

2. ***Using a "smart meter"***

This can tell us how much energy each appliance uses and what it costs. It is doing all the measuring and calculations shown above.

3. ***Energy banding diagrams.***

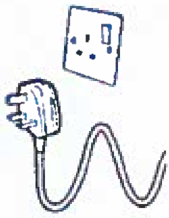


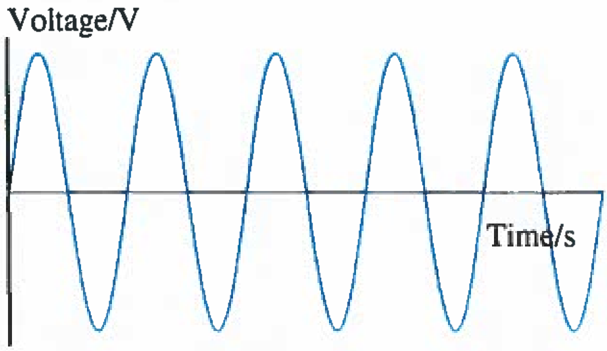
These diagrams are shown on many new electrical appliances. The band that the appliance falls into gives an idea of what it costs to run and how much energy it wastes.

This diagram is for a house and shows what the current efficiency is and how much it could be improved.

a.c. and d.c. (alternating current and direct current).

Alternating Current (a.c.)



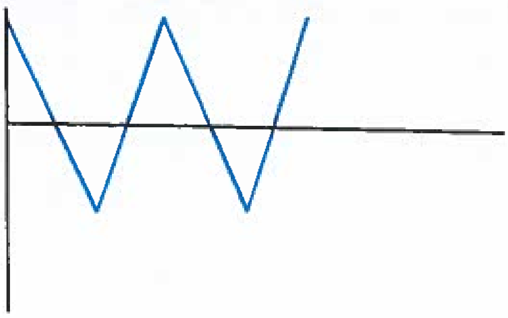


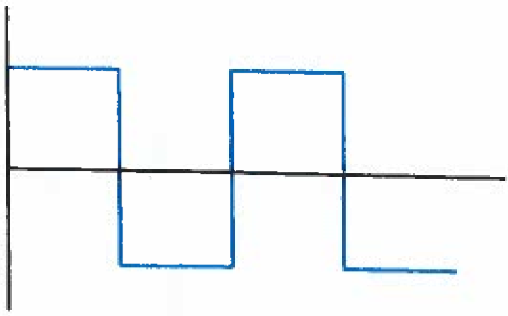
A.c. current is obtained from the mains supply. The direction of the voltage (the "push") and the direction of the current changes all the time. (50 times per second, in the U.K.)

Direction is shown by using + and - . Any voltage graph that goes from + to – shows a.c. current. (It doesn't matter what shape the graph is).

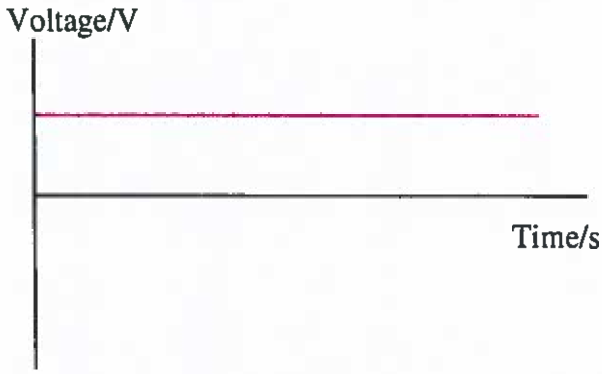
A.c. is much more dangerous than d.c. It is used because, it has lower energy losses than d.c.

The graphs below show a.c. current. The line goes from positive to negative. The shape doesn't matter.





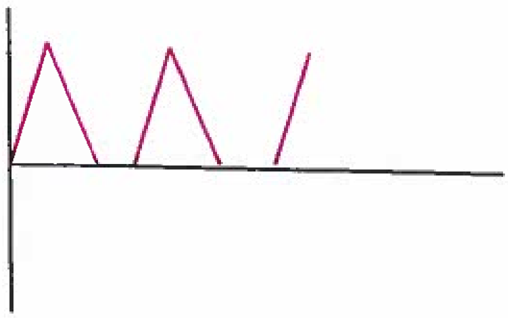
Direct Current (d.c.)



D.c. is obtained from cells and batteries, including solar cells (also known as photo-voltaic cells, or p.v. cells) and generators ***fitted with split ring commutators.***

D.c. current only flows in one direction. On a graph, it is always positive or always negative.

The graphs below show d.c. current. If the line starts of positive, it stays positive. If it starts negative, it stays negative.



Fuses and circuit breakers. Electrical Safety:

Electricity is safe as long as it only flows where it's meant to. If the insulation on wires is damaged a ***short circuit*** will allow the current to flow through other metals (and some liquids, like tap water).

This can cause fires and someone may get an electric shock (electrocution). They may get burnt or even die if the electric shock is severe enough.

Fuses and circuit breakers are automatic switches that stop the current flowing, if there is a ***short circuit***.

Fuses:

a fuse from a 3 pin plug

blade fuses, often used in cars.

a large 50a fuse from a workshop

older houses may be fitted with cartridge fuses which have replaceable wire.

- Each of these fuses has a thin piece of wire in it.
- If too much current flows, this wire will get very hot and "blow". This breaks the circuit and stops the current flowing.
- The thicker the fuse wire, the more current it will carry.
- There ***must*** be an earth wire in the circuit for the fuse to work. The earth allows a really high current to flow in ***(through the live wire)*** and out ***(through the earth wire)*** of the appliance.

Choosing the right size of fuse:

- It is important to choose the correct ***fuse rating*** for different electrical appliances.
- Too low and the fuse will blow every time you switch on.
- Too high and the appliance will not be protected, it might go on fire because the current flowing through it is too high!

There are three different fuse ratings often used at home. (The picture of the fuse wire above shows them).

They are 5A, 13A, 30A. The correct fuse for an appliance will be just above the current the appliance needs to work properly.

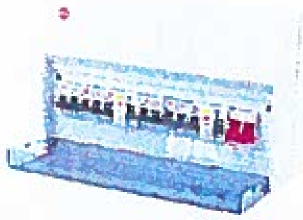
Appliance	*Operating Current/A*	*Correct Fuse Rating/A*
Phone charger	3	5
Hair dryer	10	13
Electric oven	28	30

Circuit Breakers:

There are two types of circuit breakers, ***miniature circuit breakers (mcb's)*** and ***residual current circuit breakers (rcb's).***

Miniature Circuit Breakers (mcb's).

Individual mcb



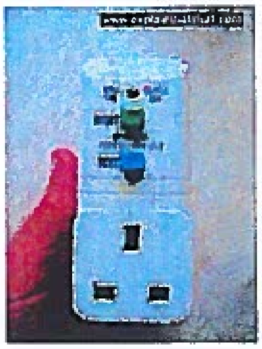
mcb's in a "fuse box"

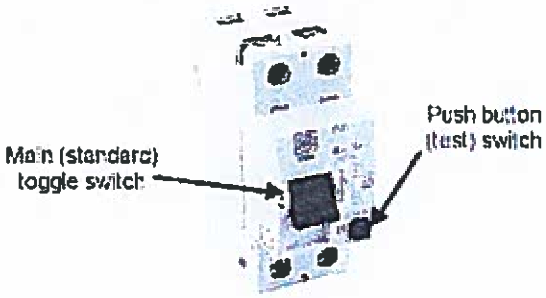
Miniature circuit breakers do the same job as a fuse, in a similar way. They ***break the circuit*** when the current flowing through them gets too high.
The advantage of mcb's is that they can be reset, just by flicking a switch. Fuses must be replaced with a new fuse.

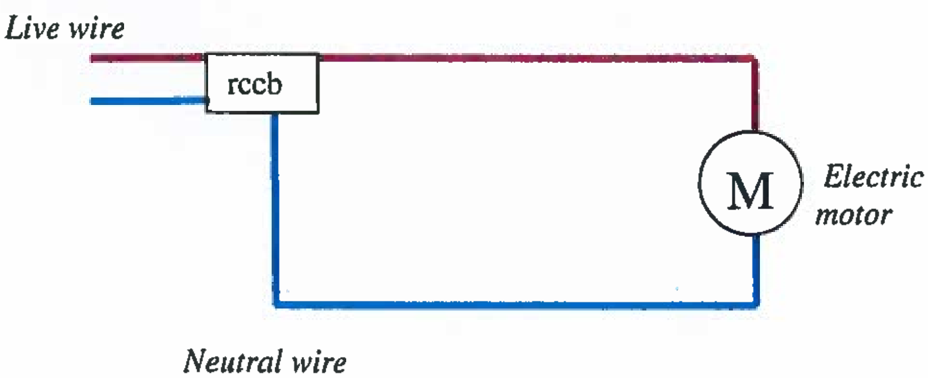
Fuses and mcb's are not perfect!
Both take quite a high current to make them work. Fuses, in particular, may take several minutes to blow.
This is a problem because, an a.c current of 50mA (0.05 A) can kill a human being.

Residual Current Circuit Breakers (rccb's).

- *Rccb's are designed to overcome the safety problems with fuses and mcb's.*
- *They can "trip" at a current of 30mA, less than the current that can stop a human heart.*
- *They can break the current very quickly (typically taking between 0.1s and 0.01s)*







- The rccb is wired between the live wire and the neutral wire.
- It detects even a tiny difference in the current flowing in, through the live and out, through the neutral.
- The rccb can be set to trip when any difference in current reaches a certain size.
- If there *is* a difference in the current flowing in and out, there **must** *be a short circuit.*
- *Rccb's don't need earth wires.*

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**

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

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

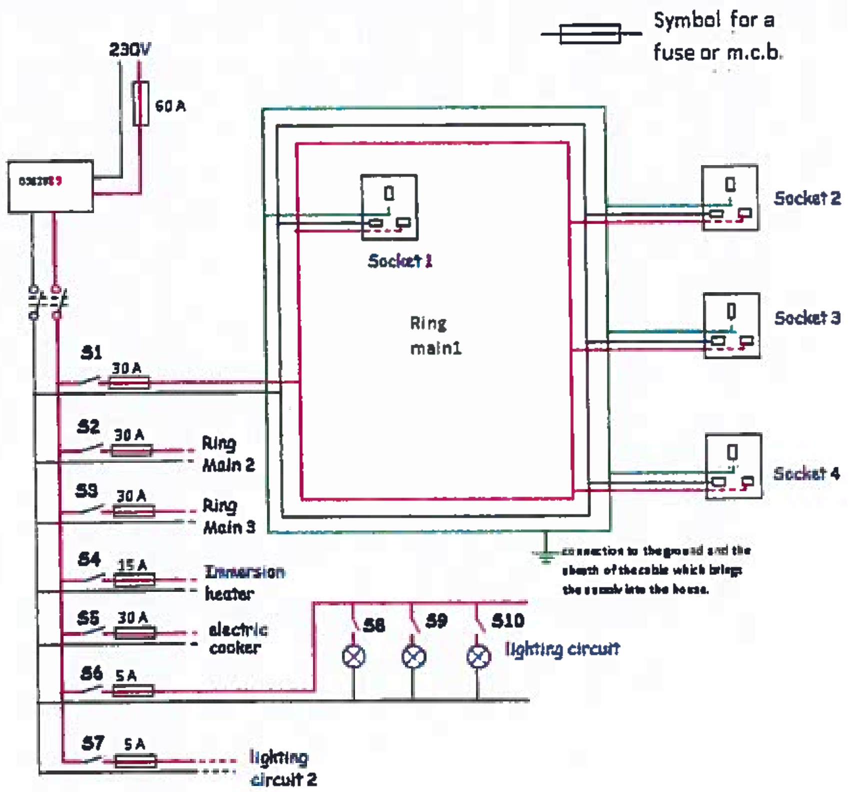
Power = current^2 x resistance

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= <u>230 V</u>

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

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

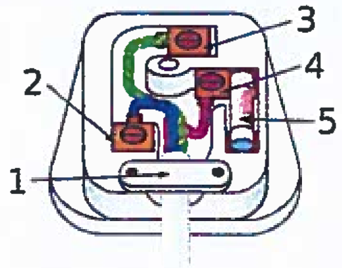
$P = V \times I$
= 230 x 30
= <u>6900 W</u>

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

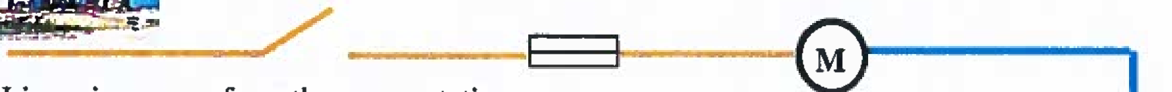
Power = voltage x current = 230 x 0.15 = <u>34.5 W</u>

Domestic Electricity – Live Neutral and Earth

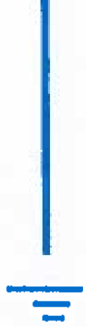


Live wires are coloured brown
Neutral wires are blue
Earth wires are green/yellow

The earth wire should never carry a current – see below



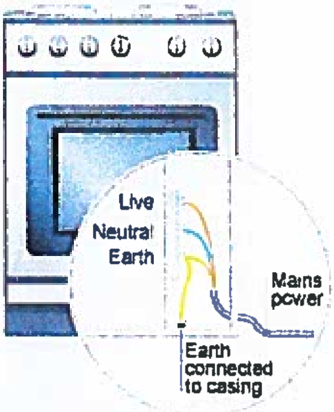
- Live wires come from the power station.
- In domestic circuits the live wire is at 230V.
- Switches, fuses and circuit breakers (mcb's) should be on the live wire.



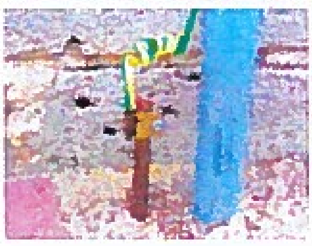
The live and neutral wires "complete the circuit"

- Neutral wires run from the appliance to an "earth" connection in the nearest sub-station
- Neutral wires should be at 0V

The earth wire is not connected to any working part.



- The earth wire is only connected to the metal casing of an appliance.
- Appliances with plastic casings don't need an earth wire and often only have two wires going to them (live and neutral).
- The earth wire is for safety only. It only carries a current if the insulation on the live or neutral wires is damaged and the bare wire touches the metal casing.
- An appliance fitted with an earth wire ***must*** be part of a circuit that includes either a fuse or circuit breaker.
- The earth wire has a really low resistance, so a really high current will flow through it. This is why fuses "blow" when there is a short circuit *(see next page)*.



The other end of an earth wire is buried in the earth in your garden

Comparing the costs

Example from a past paper

1. A householder is considering using a **renewable** energy source to help him save money on electricity bills. He used some information from a local store to draw up the following table.

	Installation cost (£)	Saving per year (£)	Payback time (years)	Maximum power output (W)	Conditions needed
Wind turbine	1200	600	2	5400	Average wind speed 4 m/s, (maximum 12 m/s)
Roof top photovoltaic cells (PV) of area 4 m^2	14000	....	7	1800	South-facing roof

(a) What is meant by a renewable energy source ? [1]

(b) (i) Complete the table by calculating the saving per year for the roof top Photovoltaic cells (PV). [1]

(ii) Give reasons why the payback times for the wind turbine and roof top photovoltaic cells (PV) may be different from both those shown in the table.[3]

(iii) Calculate the area of roof top photovoltaic cells (PV) needed to produce the same maximum power as a wind turbine.[2]

(c) Explain how the introduction of roof top photovoltaic cells (PV) and wind turbines would benefit the environment. [2]

Answers

(a) Easily replaced / replenished / will not run out / sustainable

(b) (i) [£] 2000

(ii) Wind - variable wind speed (1) Solar - hours of sunshine / roof may not face South or intensity of Sun (1) Fuel costs could change (1)

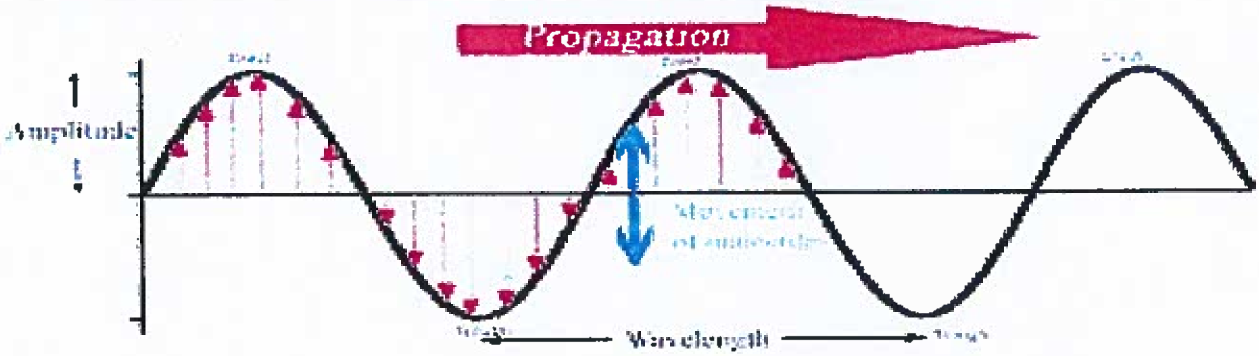
(iii) $5400 \div 1800 = 3$ (1 mark)

$3 \times 4 = 12\ m^2$ (1 mark)

(c) Reduces CO_2 (1) which reduces the greenhouse effect / global warming (1) or Less SO_2 (1) which results in less acid rain (1) or
Use less fossil fuels (1) so less extraction needed / less CO_2 / less SO_2 (1)
("less pollution" not accepted as it's not specific enough).

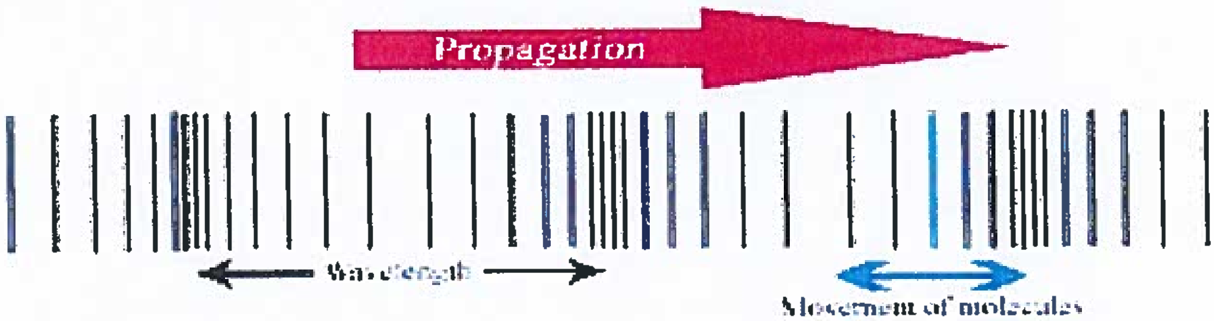
Unit 2 - Properties of waves + Structure of the Earth

Transverse: ***The oscillations of the particles are at right angles (90°) to the direction of travel (propagation) of the wave.***



Examples: All electromagnetic waves (Light, microwaves etc), S-waves,

Longitudinal waves: ***The oscillations of the particles are in the same direction as the wave is moving.***

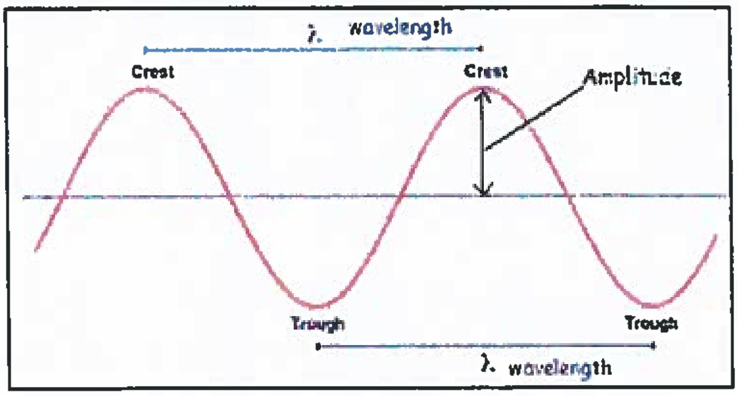


Examples: Sound waves, P-waves

Characteristics	What is it?	Units
1. Wavelength λ	The distance from a crest to the next crest or the distance it takes to repeat itself. If there are 10 waves in 5 metres then the wavelength is 0.5m	Metres, m
2. Frequency f	The number waves per second. 1 Hz is 1waves per second. If there are 40 waves in 10 seconds then the frequency is 4 Hz.	Hertz, Hz
3. Amplitude	Distance from the middle of the wave to the crest/top. The greater the amplitude the more energy the wave is carrying.	Metres, m

Characteristics of waves. (what can we measure)

Waves transfer energy from one place to another. e.g water waves, light and sound.

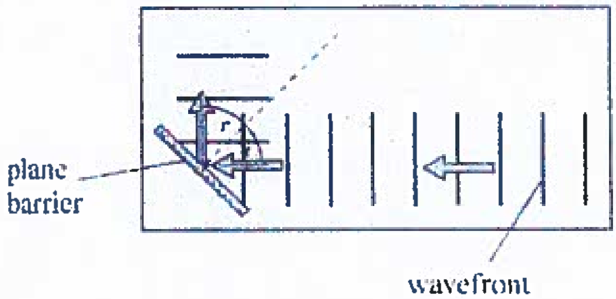


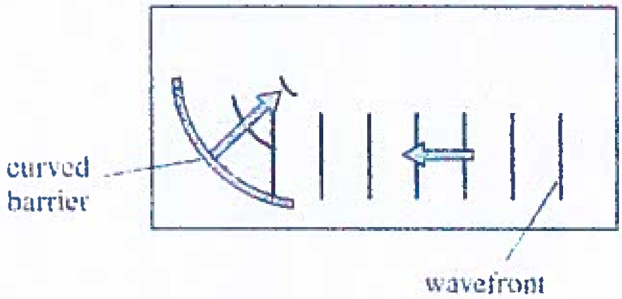
Characteristics	What is it?	Units
1.Wavelength λ	The distance from a crest to the next crest or the distance it takes to repeat itself.If there are 10 waves in 5 metres then the wavelength is 0.5m	Metres, m
2. Frequency f	The number waves per second. 1 Hz is 1waves per second. If there are 40 waves in 10 seconds then the frequency is 4 Hz.	Hertz, Hz
3. Amplitude	Distance from the middle of the wave to the crest/top. The greater the amplitude the more energy the wave is carrying.	Metres, m
4. Speed c	The distance travelled by the wave in 1 second.	Metres per second, m/s.

Properties of waves

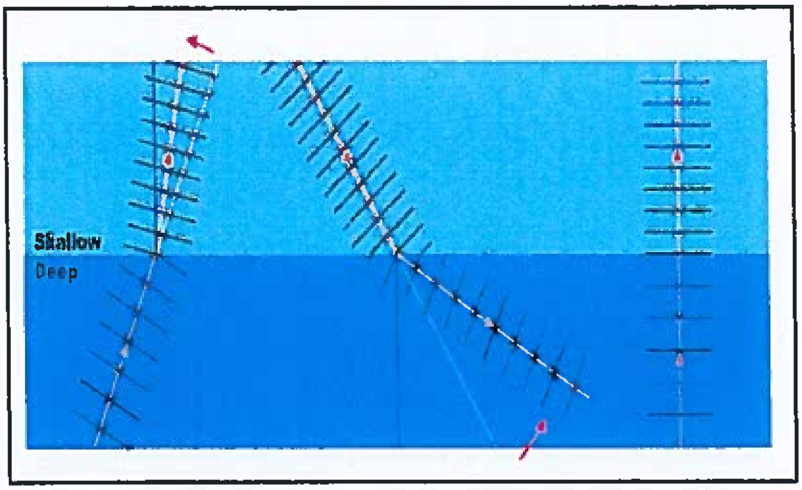
Reflection. As the waves strike a plane (flat) barrier they are reflected. This is very similar for a beam of light reflecting on a plane mirror. If a curved (concave) barrier such as a satellite dish is used, the waves can be made to converge (concentrate) at a point. The angle of incidence and reflection will be equal.

Reflection on a satellite dish.



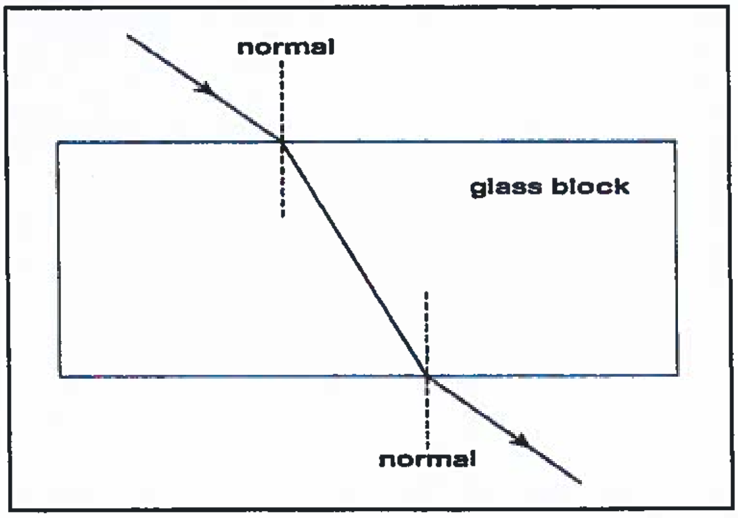


Refraction: Refraction is the change in direction of a wave at the boundary between two materials. This is caused by a change in speed.



Water. This occurs when water waves pass between deep and shallow water. The waves move more slowly in shallow water. The ***frequency of the waves remain constant*** and so the wavelength decreases. When the waves move from shallow to deeper water, their speed increase and they change direction away from the normal

Light. When light passes in between materials of different optical densities, it causes the light ray to refract. When the light moves from air to glass it slows down, and bends towards the normal. When the light emerges from the glass block it speeds up and bends away from the normal (opposite direction).



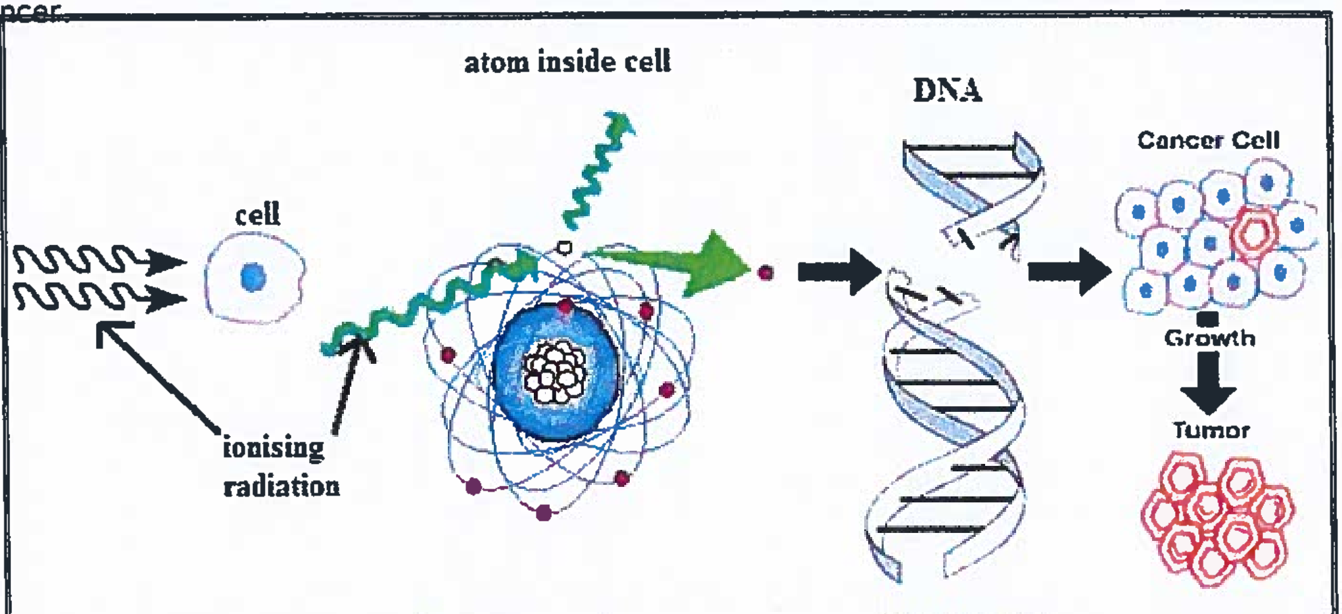
Uses of the em spectrum.

Part of em spectrum	Properties/dangers.	Uses
Radio	Longest wavelength, no known dangers.	Radio and television signals.
Microwave	Short wavelength. Some concern that they pose a health risk to phone users. Absorbed by water molecules.	Heating food, satellite and mobile phone communication.
Infrared (thermal radiation)	Longer wavelength than visible light. Can burn if you get too much exposure.	Transmitting information in optical fibres, remote controls and infrared cameras
Visible light	If the light is too bright it can damage the eye/retina.	Photosynthesis. Lasers in CD players.
Ultraviolet	Can ionise cells in the body leading to skin cancer.	Sun tan beds, detecting forged bank notes.
X-rays	They are ionising which can lead to cancer.	Medical imaging, inspection of metal fatigue and airport security.
Gamma	The most ionising in the em spectrum because they have the most energy.	Cancer treatment - killing cancer cells and sterilising medical equipment or food.

Radiation emitted by objects. (Higher tier only)

Ionising radiation.

Ionising:- some particles and electromagnetic waves (both are radiation) have enough energy to rip electrons away from atoms and molecules. Ions are formed which can interact with cells in the body and ***damage DNA/cells***. This damage can lead to the formation of cancer.

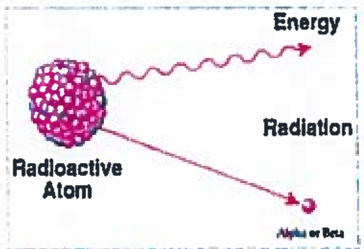


Development of cancer from mutation produced by ionizing radiation

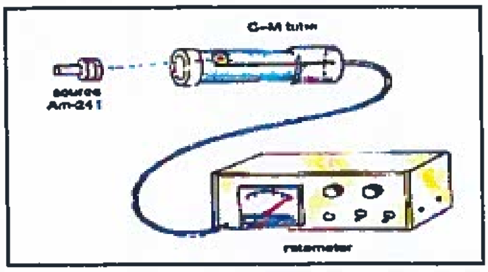
Ionising radiation include: alpha, beta, gamma, x-rays and ultraviolet.

Non-ionising radiation: visible light, infrared, microwave and radio waves.

Radioactive decay:



Some atoms are unstable and so we say that they are radioactive. They try to become stable emitting alpha, beta or gamma radiation. The process of atoms undergoing radioactive decay is totally **random** and **spontaneous**. There is no way of telling **when** or **which** atom will decay in a radioactive material.



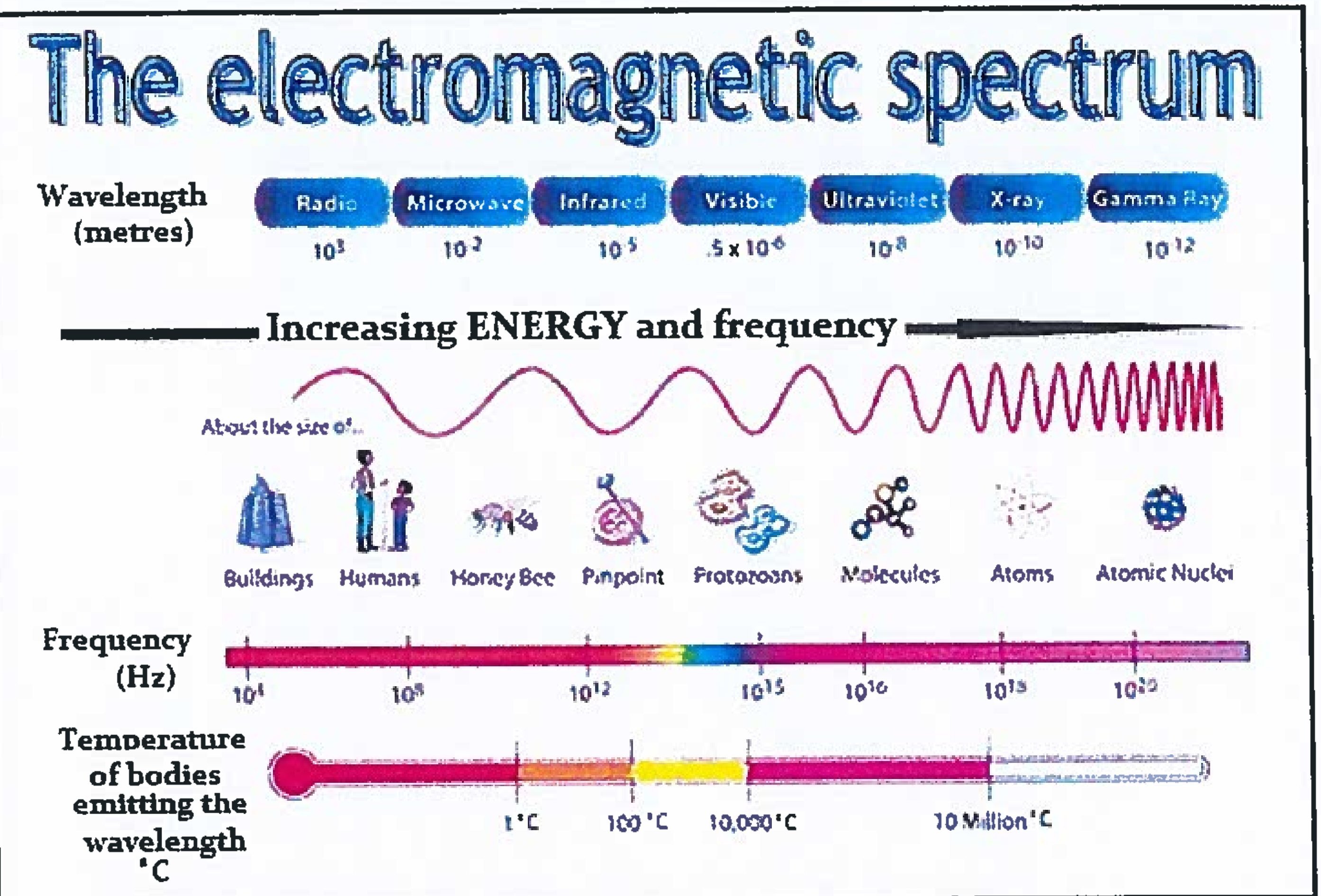
A Geiger counter can be used to measure the ionising radiation. To gain greater accuracy when measuring radioactive decay we must do 2 things:

1. Repeat the experiment and calculate the average.

2.Carry out the experiment over a longer period of time.

The electromagnetic spectrum.

A family of waves that have similar properties.



The frequency and energy increase from radio to gamma.

The wavelength decreases from radio to gamma.

Note: they do not have to arrange the spectrum in this order, they could do it starting with gamma on the left (it would still have the most energy).

Common properties of the electromagnetic spectrum:

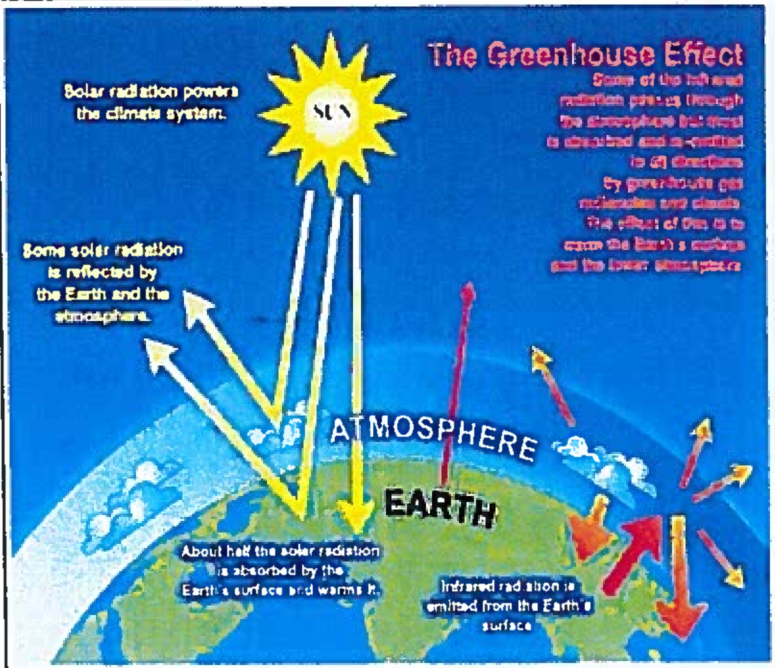
1. **Travels at the same speed in a vacuum. (300,000,000 m/s or 3×10^8 m/s)**

2. **Transfers energy/information from one place to another.**

3. **They are transverse waves.**

The greenhouse effect. (higher tier only)

1. ***Visible light*** passes through the atmosphere.
2. The Earth absorbs sunlight, and then emits the energy back out as ***infrared/thermal*** radiation.
3. Some of this infrared/thermal radiation makes it into space.
4. Some infrared radiation is absorbed in the atmosphere, by carbon dioxide, methane gas and water vapour.
5. These gases then ***re-emit*** the infrared/thermal radiation.
6. The heat that doesn't make it out through Earth's atmosphere keeps the planet warmer than it would be without the atmosphere which can lead to ***global warming***.



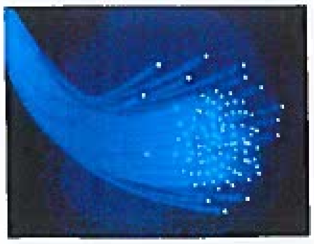
http://www.global-greenhouse-warming.com

Greenhouse gases: *carbon dioxide, water vapour, methane and CFC's*.

The levels of CO_2 in the atmosphere are increasing because?

1. Burning of fossil fuels.
2. Large areas of forest are being cut down for timber and to gain more farm land.

Comparing forms of communication.

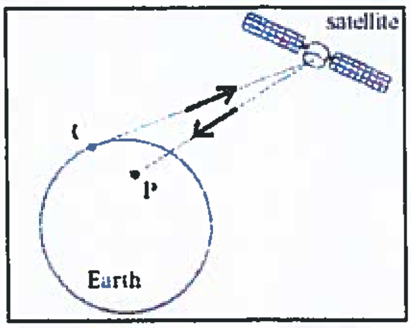


Optical Fibres. The signal is sent using **infrared** light because it can travel further within the cable than visible light. These cables are laid between the continents. The signals travel at 200,000,000 ($2x10^8$) m/s and can carry more information (1.5 million phone calls through one cable).

The advantages of optical fibre over traditional copper cables are

1. They require fewer boosters to increase strength of the signal.
2. More difficult to bug (tap into) the signal.
3. They weigh less.
4. Use less energy.
5. No interference from neighbouring cables.

Satellites.



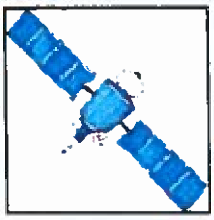
Communication satellites need to be in a **geosynchronous orbit** (36,000 km high) because Satellite needs to be above a fixed point on the Earth so satellite dishes (e.g. sky dish) do not have to be moved.
They use **microwave** radiation to send signals to the satellite

Definition of geosynchronous orbit: the satellite is remains above the same point on the Earth's surface (above equator) and takes 24 hours to complete an orbit (which is the same as the Earth's period of rotation).

To send a signal from C to P, the signal must travel from C to the satellite and relayed back to P. To send a signal a greater distance then more than 1 satellite can be used.

There is less time delay with optical fibres and they are not affected by the weather.

Time delay: It's possible to calculate the time delay when sending information.



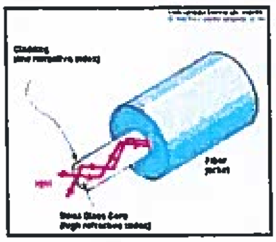
Method 1, satellite: If the distance from the Earth's surface to each satellite is 3.6×10^7 m, what is the total distance the microwaves must travel to go from Wales to Italy?

Total distance (up and down once) = $2 \times 3.6 \times 10^7 = 7.2 \times 10^7$ m

Microwaves are electromagnetic waves so travel at 3×10^8 m/s.

$$\text{Time} = \frac{\text{distance}}{\text{speed}} = \frac{7.2 \times 10^7}{3 \times 10^8} = 0.24 \text{ s}$$

Method 2, optical fibres: The distance from Wales to Italy is about 2000 km = 2×10^6 m. Infrared waves travel at about **70%** of the speed of light in an optical fibre. What is the speed of infrared waves in an optical fibre?



$$70\% \text{ of } 3 \times 10^8 = \frac{70}{100} \times 3 \times 10^8 = 2.1 \times 10^8 \text{m}$$

$$\text{Time} = \frac{\text{distance}}{\text{speed}} = \frac{2 \times 10^6}{2.1 \times 10^8} = 0.0095 \text{ s}$$

So there is less time delay with the optical fibre (although the signal will need to be boosted, which can increase the delay time).

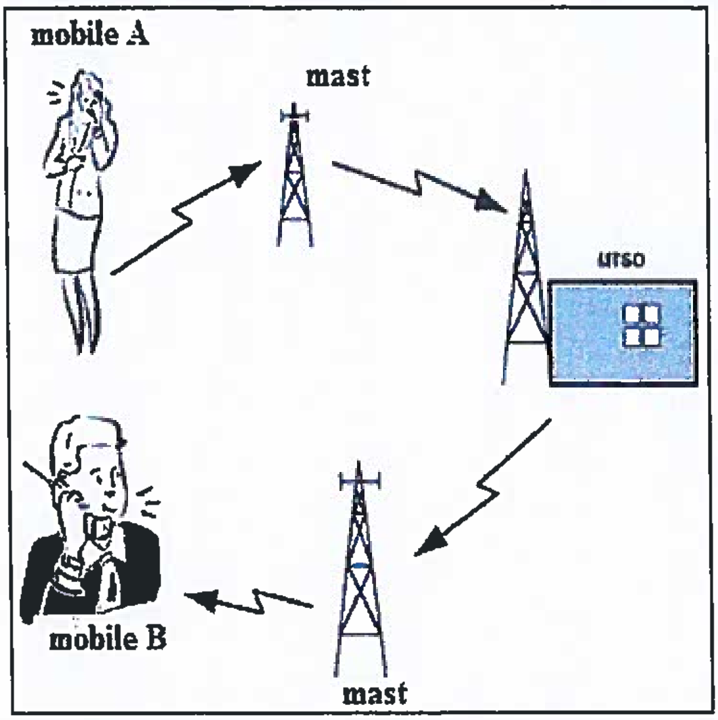
Mobile phones: Mobile phones work by communicating with the nearest phone mast, and then the base station

Your phone is constantly searching for the strongest signal. If there is no signal "no network" appears.

The MTSO (mobile telephone switching station) tracks your movement all the time.

When a friend phones, the MTSO searches to see which mast to use.

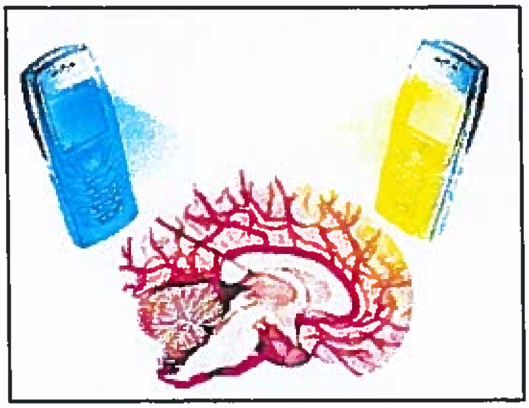
If you move away from the mast the MTSO searches for a new mast.



Which communication method is best?
There are a number of factors to consider: set up cost, maintenance, time delay and the bandwidth.

Mobile phone dangers.

The evidence is not very clear about the dangers of mobile phones. Scientific studies need to have a large sample and also be reproducible (other scientists get similar results) for the data/information to be reliable/dependable.



You can reduce the risk by:

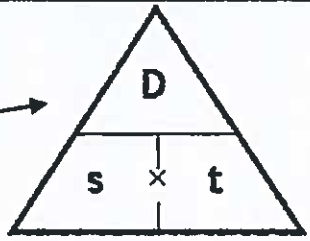
- Keep the phone calls as short as possible.
- Using hands-free devices
- Using the phone outside so the signal doesn't have to be as strong.

Questions on the dangers will be reading a given passage (comprehension) style questions.

Calculations involving waves.

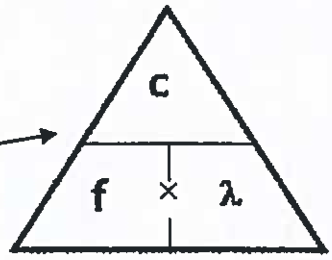
The speed of a wave can be calculated in 2 ways.

1. Speed = $\frac{\text{distance}}{\text{time}}$



2. wave speed = frequency x wavelength

$c = f\lambda$



Example 1: A gun is fired and person 1200m away hears the shot 4 seconds after the gun is fired, what is the speed of the sound wave? Since distance and time is given we must use the first equation (always show your working).

Speed = $\frac{\text{distance}}{\text{time}} = \frac{1200}{4} = 300$ m/s

Example 2: A water wave moves at a **speed** of 2.5 m/s. Its **wavelength** is 7.5 m. Use the correct equation from to calculate the **frequency** of the wave. We use the 2nd equation since speed and wavelength are given.

Speed = frequency x wavelength

Rearrange the equation, frequency = $\frac{\text{speed}}{\text{wavelength}} = \frac{2.5}{7.5} = 0.33$ Hz

Example 3: Light from the sun travel a 150,000,000 km at a speed of 300,000,000 m/s (3×10^8 m/s). Calculate the time in minutes it takes for the light to reach us here on Earth.

We have to units to change here: 150,000,000 km, into metres

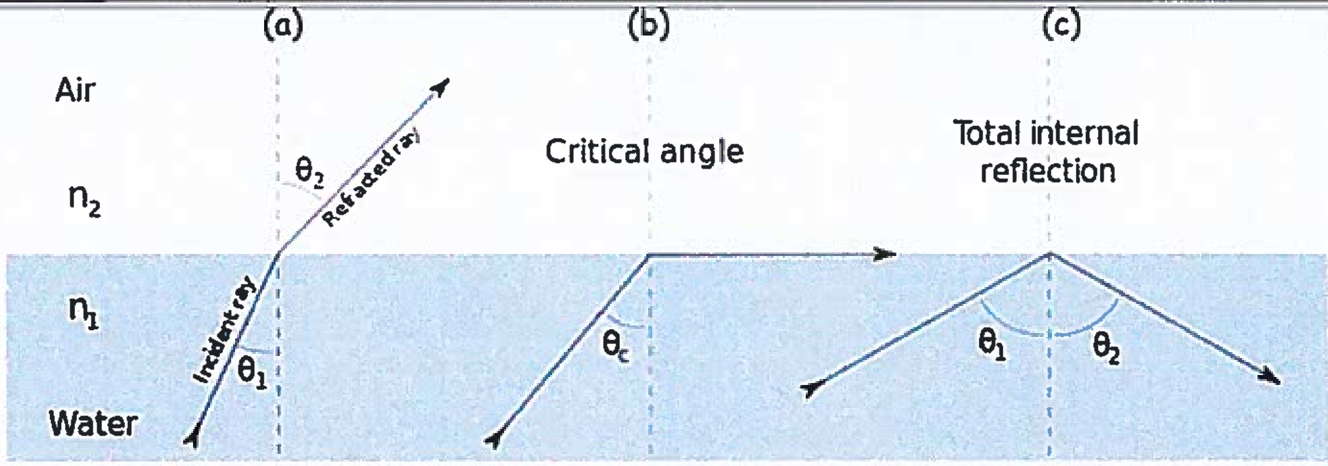
150,000,000 km x 1000 = 150,000,000,000 m or 1.5×10^{11} m

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

time = $\frac{\text{distance}}{\text{speed}} = \frac{150{,}000{,}000{,}000}{300{,}000{,}000} = \frac{1.5 \times 10^{11}}{3 \times 10^8} = 500$ s

Changing seconds into minutes: $\frac{500}{60} = 8.3$ minutes

Total internal reflection



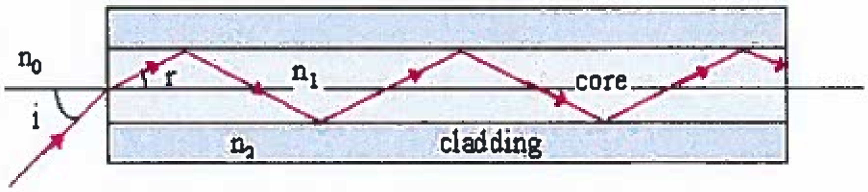
This phenomenon occurs when light moves from a more optically dense material (e.g. water) to a less optically dense material (e.g. air) causing a change in speed.

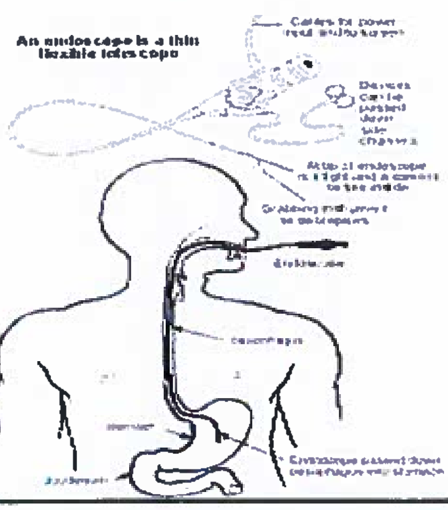
1. The incident angle θ_1 is *less than* the critical angle and so the light ray refracts/ bends away from the normal as it emerges from the water. θ_2 is the **angle of refraction.**
2. The incident angle θ_1 ***equal*** to the critical angle and so the light ray passes along the surface of the boundary.
3. The incident angle is ***greater than*** the critical angle and so the light ray is reflected back into the water. This phenomenon is known as ***total internal reflection.***

$\theta_1 = \theta_2$

Uses of total internal reflection.

Optical Fibres: these can be used to carry information by using infra-red light. There are many uses from internet, cable TV, phone, some signs





Endoscope: An endoscope is any instrument used to look inside the body. Thousands of optical fibres are bundled together in an endoscope which is inserted into a human body by the doctor. Light can be directed down the fibres even if they are bent, allowing the surgeon to illuminate the area under observation. He/she can then view this from a television camera linked to a monitor.

Optical Fibres:

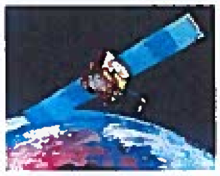
Optical fibres transfer data using total internal reflection (t.i.r.).

Uses of Optical Fibres:

Long distance communication.

Optical Fibres.

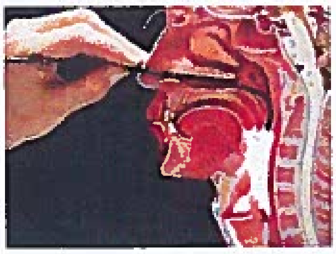
vs

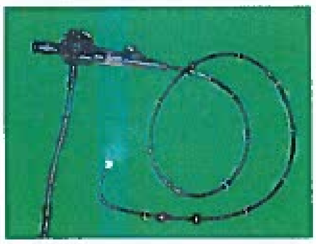


Geostationary Satellites

	Optical Fibres	Geostationary Satellites
Signal travels at the speed of light	✓	✓
Signal follows the Earth's surface	✓	✗
Signal has to travel 72 000km through space	✗	✓
Signal travels furthest	✗	✓
About 1s signal delay	✗	✓
Easiest to fix if damaged	✓	✗
Can suffer from interference due to rain clouds	✗	✓
Able to handle many times more voice and data calls	✓	✗
Likely to be most important in the future	✓	✗

Medical Examination.





Endoscopes use one optical fibre to shine light inside a patient and a second is carries the image back to a doctors eye.

CT Scans (Computerised Tomography) uses x-rays to build up an image of the insides of a patients body.

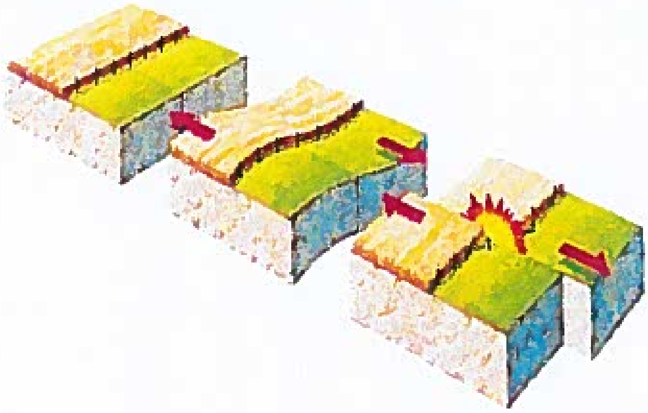
	Endoscopy	CT Scans
Uses potentially harmful ionising radiation.	✗	✓
Dangerous if used too often.	✗	✓
Can be used to take samples for examination (biopsies).	✓	✗
Used during operations.	✓	✗
Very large and cannot be moved around	✗	✓
Easily transportable	✓	✗
Extremely expensive	✗	✓

Seismic waves / Earthquakes

The mechanisms and processes involved when earthquakes occur are extremely complex. However some of the characteristics of earthquakes can be explained:

- Over time stresses in the Earth build up (often caused by the slow movements of tectonic plates)

- At some point the stresses become so great that the Earth breaks ... an earthquake rupture occurs and relieves some of the stresses (but generally not all) and a lot of **energy** is released.

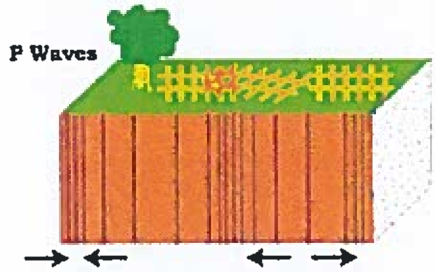


The 3 types of seismic waves.

Earthquakes result from P, S and surface waves generated by the release of energy stored in rocks on either side of a fault.

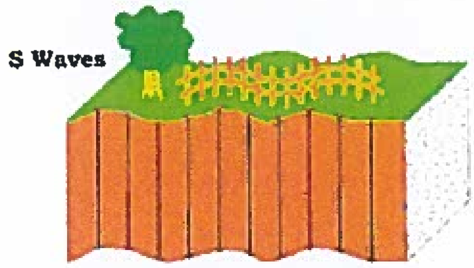
Primary (P) Waves. They are called primary waves because they arrive first. The main characteristics of primary waves are:

- They are longitudinal waves.
- Faster than S waves.
- Can travel through ***liquids*** and ***solids.***



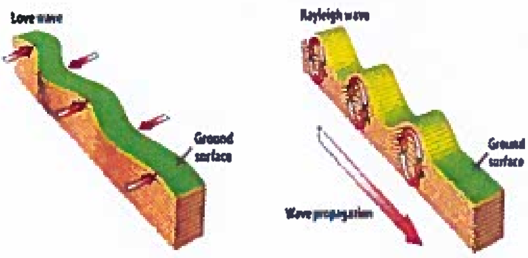
Secondary (S) Waves. They are called secondary waves because they arrive second. The main characteristics of secondary waves are:

- They are transverse waves.
- Travel slower than P waves.
- Can only travel through ***solids.***



Surface Waves: Travel along the Earth's crust. The main characteristics of surface waves are:

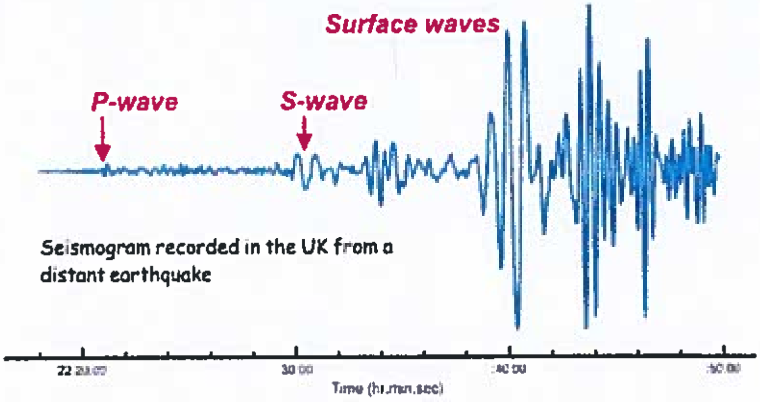
- Have higher amplitudes than P and S waves.
- These usually cause buildings to be knocked down.
- Formed from a combination of P and S waves.
- Generally slowest of the three waves.



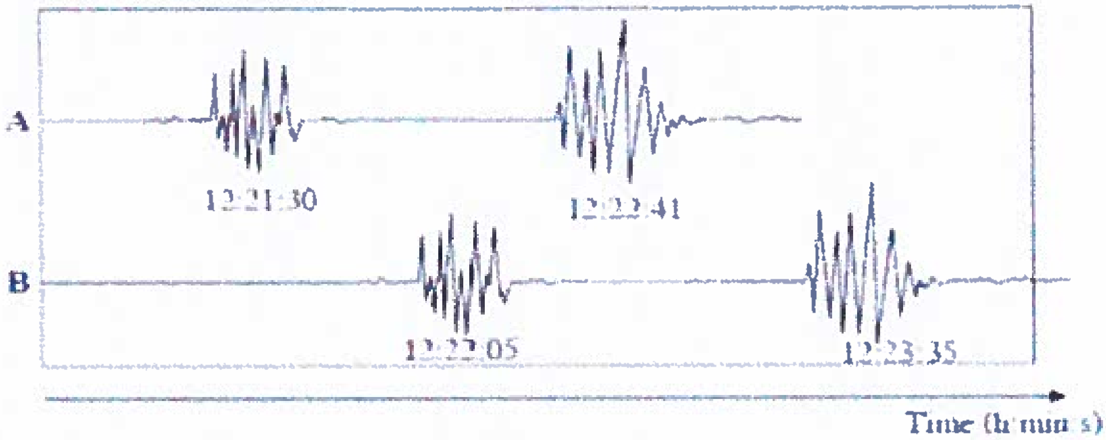
Seismogram.

Seismograms can be used to locate the epicentre of an earthquake.

P-waves arrive first then S-waves followed by the surface wave. The greater the distance from the earthquake to the monitoring station the greater the time lag/gap between the waves. Remember not all monitoring stations will receive the seismic waves due to the shadow zones.



Example question. The diagram shows the first seismic signals received from an earthquake at two monitoring stations A and B.



1. What evidence is shown by the seismic data that suggests A is nearer the epicentre than B?

   Answer: The seismic waves arrive at A before they arrive at B.

2. What evidence suggests P and S waves have travelled with different speeds from the earthquake?

   Answer: P and S waves do not arrive at the same time.

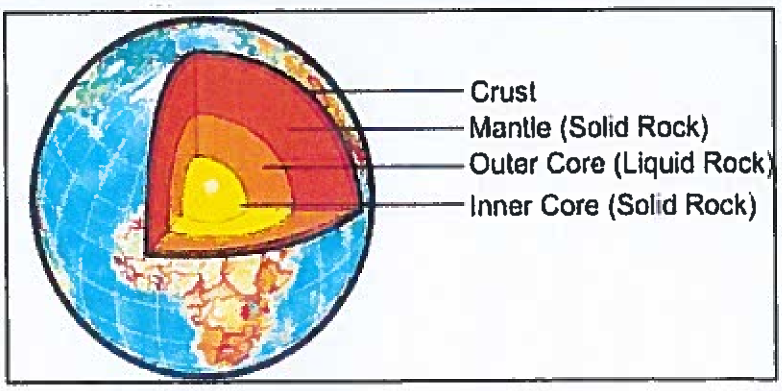
3. The time lag between the arrival of the P and S waves for a seismic station which is 100km from the epicentre of an earthquake is 12s. Calculate the distance of the monitoring station A from the epicentre of this earthquake.

Answer : 1st step is to work out the time gap between P and S waves for station A. Between 12:21:30 and 12:22:41 there is a 71s gap/delay.

2nd step is to realise that there is a 12s delay for each 100km (as stated). How many times more is 12s than 71s ?

So, 71 ÷ 12 = 5.92 and then 5.92 x 100 = 592km

The velocity of a P or S wave depends on the physical properties of the rock. In fact, if the velocity of the wave can be measured, it may be possible to predict the type of rock the wave travelled through - indirect detection of rock type.

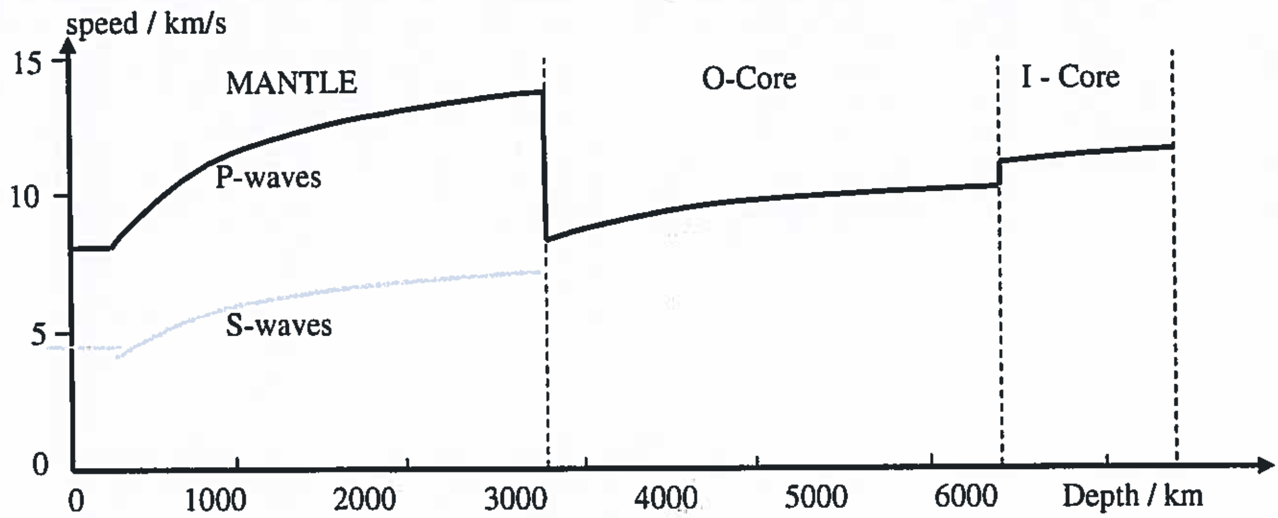


The velocity depends upon

1. **The density of the rock/material. The higher the density the more slowly waves travel.**

2. **The rigidity of the material - waves travel more quickly more rigid/stiff materials.**

Speed of P-waves in the core: the density of the iron core is very much greater than that of the mantle, their speed is much less. As in the mantle, the speed increases with depth and the speed increases as it crosses into the more rigid solid inner core.



Rigidity of the material has a greater effect on speed than density.

Look at the graph and notice that there are no S-waves in the outer core. P-waves, S-waves and surface waves can travel in the following.

- ***Crust (solid):*** P-waves, S-waves and surface waves.
- **Mantle (solid):** P-waves and S-waves.
- ***Outer core (liquid):*** P-waves only.
- ***Inner core (solid):*** P-waves.

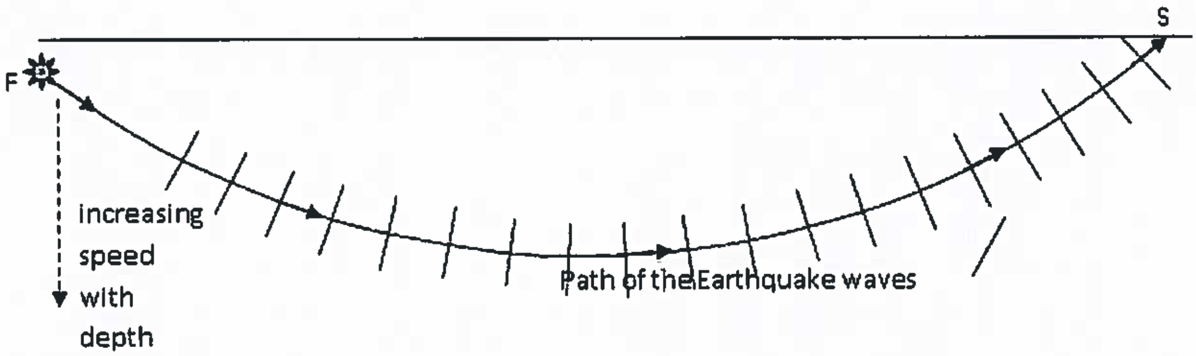
Refraction of seismic waves.

Both the density and stiffness increase with depth in the mantle, but the rigidity wins and so the speed of both S- and P-waves increases with depth. If the speed of the waves changes then the waves will refract and so will change direction.

Refraction in the Mantle Over a few hundred km refraction has the following effect - ignoring the curvature of the Earth:

F = earthquake focus

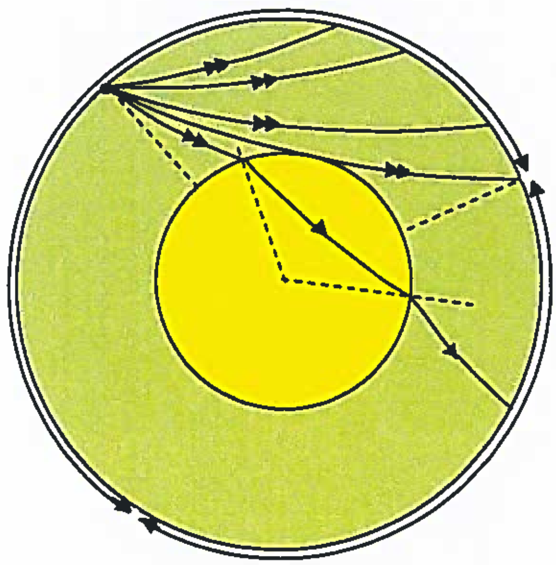
S = Seismometer



The waves curve because the bottom edge travels faster than the top edge and so it overtakes the top edge. This makes it bend upwards. Note that both P- and S-waves curve like this. They both travel faster the deeper they go into the mantle.

Inside the core.

The waves refract/bend at the core-mantle boundary because they slow down. Inside the core, the waves curve gradually, just like in the mantle, because the deeper they get, the faster they become - because the core is more rigid at greater depths. They don't refract/bend very much though because the *speed* doesn't change very much - see the graph. (The dotted lines represent the normal which is always at 90° to the boundary).



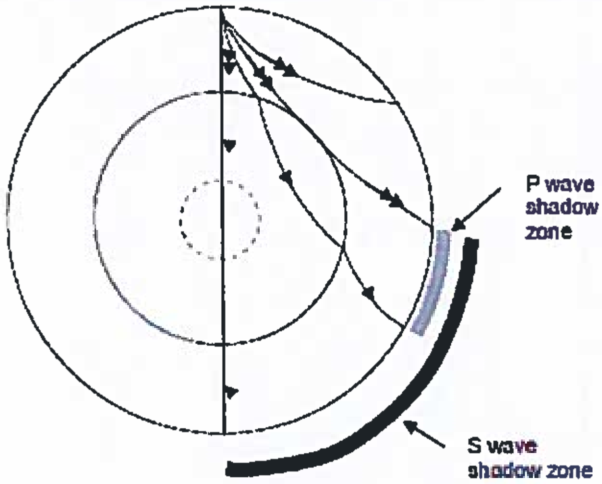
If the waves pass through the inner core, they refract again. They also ***refract*** as they pass back into the mantle.

Shadow zones.

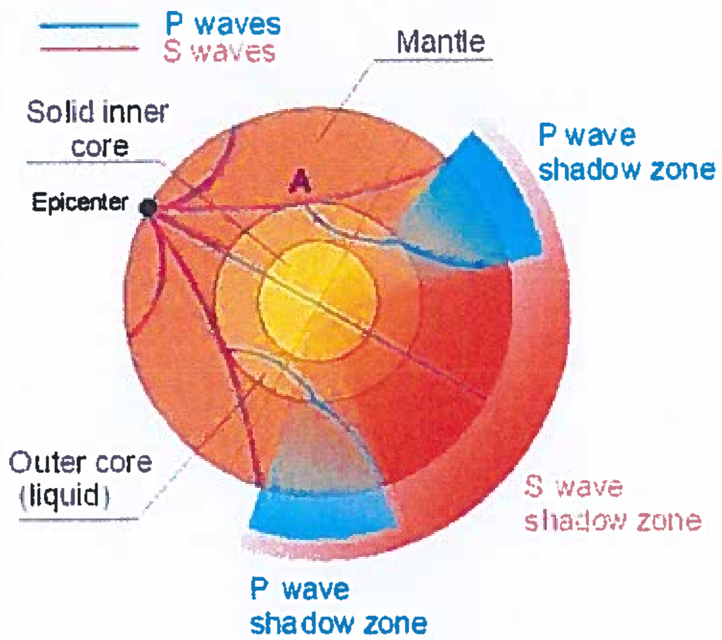
The outer core of the Earth is liquid. The mantle and the inner core are solid. Only 'P' waves can travel through the liquid outer core. By measuring 'P' and 'S' waves after an earthquake at different points across the globe, we can estimate the size of the Earth's liquid outer core.

P and S waves travel **very differently** through the Earth. Initially P and S waves travel in all directions from the epicentre of an earthquake outwards. They are refracted as they travel from the epicentre and follow arcs.
However, S waves **cannot** travel through the liquid outer core of the Earth.

1. the large shadow zone for the S waves on the opposite side of the earth from the epicentre.
2. the two smaller shadow zones for P waves



Note that there is a considerable change in density from the solid mantle to the liquid outer core. By finding the angles at which the P and S waves **both** disappear we can calculate the radius of the liquid core of the earth.



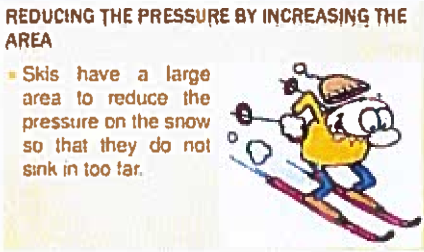
The existence of the ***S shadow zone*** is due to a liquid outer core [at all angles > 104° from the epicentre] shows that there must be a molten layer (liquid) and gives evidence for its size.

The size of the ***P shadow zone*** reveals the amount of **refraction** at the core - hence gives evidence for its density / rigidity.

Unit 4 - Gases & the Kinetic Theory

Pressure

Pressure is a measure of how spread out or concentrated a force is on a surface. For example, when walking on soft snow, a person wearing normal shoes is likely to sink into the snow because the force (the person's weight) is acting on a fairly small area. This leads to a relatively high pressure on the snow. If the same person wears snow-shoes, the pressure is less since the same weight is spread over a larger area.



Here's the equation relating force, area and pressure :

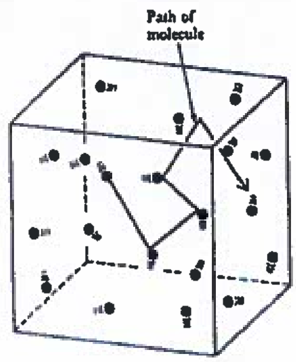
$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \qquad P = \frac{F}{A}$$

where	force is measured in	newtons, N
	area is measured in	m^2 (or sometimes cm^2)
and so,	pressure is measured in	N/m^2.

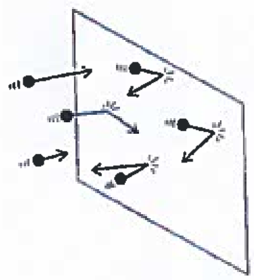
Another common unit for pressure is **Pascal, Pa**, but only if the area is measured in m^2 (rather than cm^2).

The kinetic theory

The kinetic theory is simply the idea that a gas is made from tiny particles that are in constant, random, motion. These particles are assumed to be widely spread and to move in straight lines in between collisions. All collisions are elastic - meaning that <u>no</u> kinetic energy is 'lost' during collisions.



A gas may be pictured as a collection of widely spaced molecules in continuous, chaotic motion.



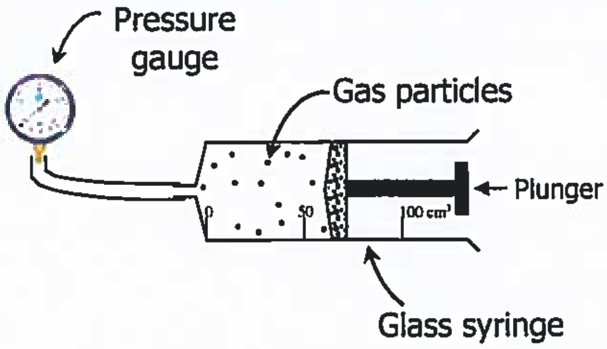
As the molecules of a gas collide with the walls of their container, they exert a force on it. The average force per unit area is the pressure of the gas.

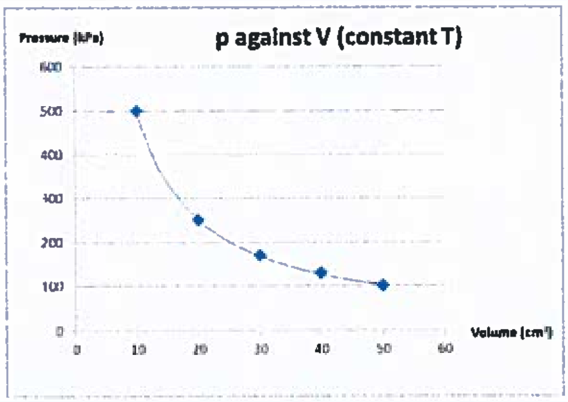
In gases, pressure is created by the gas particles colliding with the inside surface of the container. Every time a particle collides with the inside surface it creates an outward force on the container wall. Millions of such collisions on each square centimetre every second produces outward 'pressure'.

Pressure, Volume & Temperature

A) Relationship between pressure and volume.

The simple experiment below investigates how changing the volume of a gas affects its pressure. **Temperature is kept constant.**
As the plunger is forced inwards (where the volume decreases), the pressure gauge registers an increase in pressure. The graph on the right shows the results.



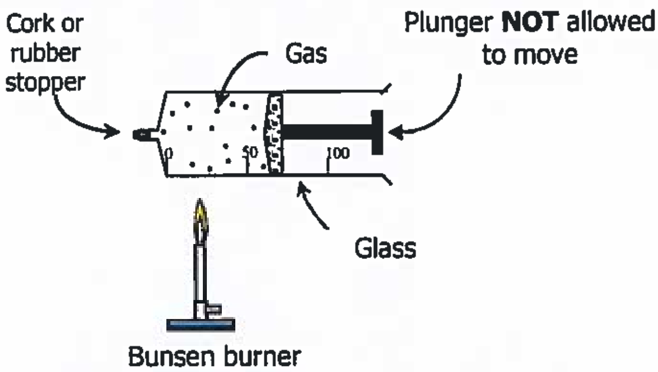


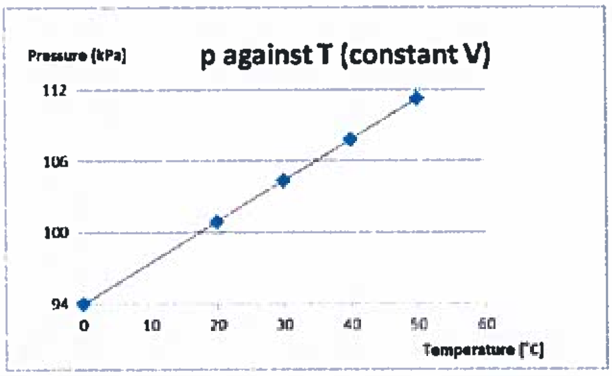
As the volume decreases, the pressure increases. In fact, you can see from the graph that if the volume <u>halves</u>, the pressure <u>doubles</u>. This means that pressure is inversely proportional to the volume, and hence we can write:

$$p \times V = \text{constant}$$

B) Relationship between pressure and temperature.

This time the **volume is kept constant.**
As the temperature of the gas is increased, the pressure gauge registers an increase in pressure. The graph on the right shows the results.



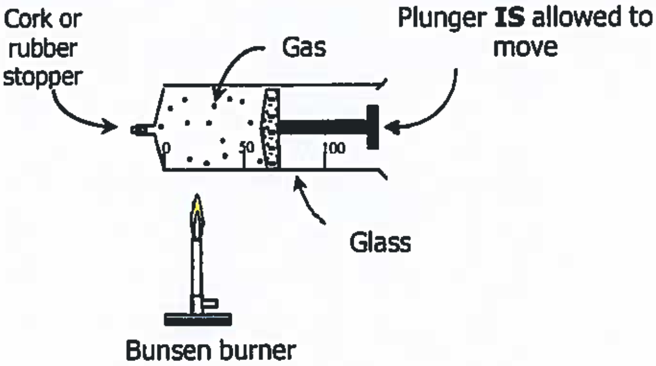


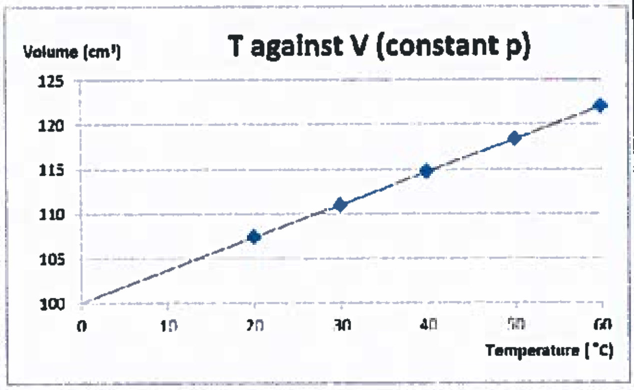
If the temperature is measured in KELVIN rather than degrees Celsius (see later on !), the graph would show that the pressure <u>doubles</u> when the temperature <u>doubles</u>. This means that pressure is directly proportional to the temperature, and hence we can write :

$$\frac{p}{T} = \text{constant}$$

C) Relationship between temperature and volume.

This time the **pressure is kept constant.**
As the temperature of the gas is increased, the volume increases. The graph below shows the results.





If the temperature is measured in KELVIN rather than degrees Celsius (see later on !), the graph would show that the volume doubles when the temperature doubles. This means that volume is directly proportional to the temperature, and hence we can write :

$$\frac{V}{T} = \text{constant}$$

Combining the three results

If we combine all the results/conclusions from the three 'experiments', we get the following result :

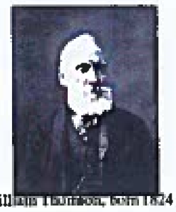
$$\frac{pV}{T} = \text{constant} \quad \text{or} \quad \frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

Note
Strictly speaking, this is only true for an "Ideal" gas where the particles don't affect each other **in between** collisions, and their size is extremely small in comparison to their (average) separation. However, this 'ideal gas equation' works very well in most every-day situations.

Temperature


William Thomson, 1846

Once scientists realised that there is a direct link between the temperature of a gas and the average kinetic energy of the particles in that gas, they also realised that there must be a minimum temperature. This minimum temperature is known as **absolute zero**, and occurs when the (average) kinetic energy of the particles is zero, i.e. they stop moving !


William Thomson, born 1824

This led Lord Kelvin (aka William Thomson) to propose a new scale for temperature :

The Kelvin scale is defined so that zero Kelvin, or '0 K' is the temperature of absolute zero, and that a change of 1 °C is the same as a change of 1 K.

This then means that the freezing point of water is about 273 K, and the boiling point of water is 373 K.

Any equation used in this section only works if the temperature is measured in kelvin, K.

Example

A can of baked beans is mistakenly left sealed and placed in an oven. The air above the beans is initially at room temperature, 18 °C, and atmospheric pressure (100kPa). Calculate the pressure of the air inside the can when its temperature reaches 220 °C. (Assume there's no change in volume).

First we must convert the temperatures to kelvin using the following information seen on page 2 of the exam. paper :

$$T / \mathrm{K} = \theta / {}^\circ\mathrm{C} + 273$$

18 °C = 18 + 273 = 291 K
220 °C = 220 + 273 = 493K

Since volume is constant, $\frac{p_1}{T_1} = \frac{p_2}{T_2}$

Re-arranging : $p_2 = \frac{T_2 p_1}{T_1} = \frac{493 \times 100\,000}{291} =$ **169 415 Pa**

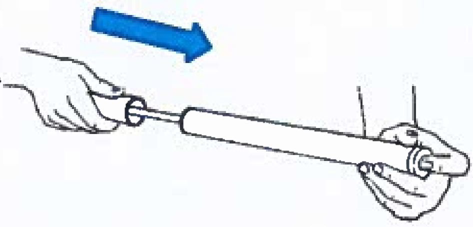
Note : This is likely to cause the can to explode, so do <u>not</u> try this at home !!! ;-)

Variation of pressure with volume or temperature

Explaining a change in pressure due to a change in volume

When the volume of a gas is decreased (i.e. the gas is compressed) the pressure increases.

To visualise this, imaging holding a bicycle pump with the air-hole at the top of the pump blocked - the gas (air) inside the pump is now sealed. If you were to push the piston/handle of the pump inwards, you're decreasing the volume of the air inside. This would cause the pressure of the gas inside the pump to increase - you would feel this trying to push the piston/handle back out.



How can we explain this with the kinetic theory of gases ?

As the volume decreases, the same number of gas particles are moving around in a smaller space, and so they are closer together. If this is done at a constant temperature, the average speed of the particles **stays the same**. However, there are now more particles striking each unit area of the inside of the container each second. When particles strike the wall of the container there's a change in momentum of the particles (Newton's 2nd law) which results in a force on the particles and hence an equal but opposite force on the wall (Newton's 3rd law). This means that there is more force acting on the inside surface. Since $P = F / A$, the pressure will increase.

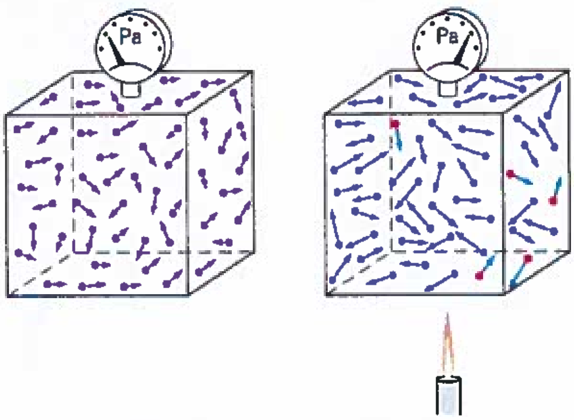
Explaining a change in pressure due to a change in temperature

When the temperature of a gas is increased the pressure increases.

How can we explain this with the kinetic theory of gases ?

As the temperature increases, the average speed of the particles increases.

This means that the particles strike the inside surface of the container **more often** than before. Also, they strike the inside surface **with greater force** than before.
Both these things mean that the particles exert more force on the inside surface. Since $P = F / A$, the pressure therefore increases.



(a) Initial temperature (b) Heat added

Heating up – Specific Heat Capacity:

Increasing the temperature of a substance needs energy. We can work out how much energy is needed by using:

Energy = mass x specific heat capacity x change in temperature.

- Energy: Joules (J)
- mass: kilograms (kg)
- specific heat capacity: Joules per kilogram degrees Celsius (J/kg^oC)
- change in temperature: degrees Celsius (^oC)

The symbol equation for this is:

$$Q = mc\Delta t$$

Where **Q** is energy (don't worry that a different letter is used)
m is mass of the substance
Δt is the ***change*** in temperature of the substance.

Δ is the Greek letter "delta". It just means "change".

Δt means "change in temperature".

Example:

How much energy is needed to raise the temperature of 500g of water from 20^oC to 35^oC? *(The specific heat capacity of water is 4 200J/kg°C)*

The task asks us to calculate energy.

<u>Data</u>

Q = ?

m = 500g = (500 ÷ 1000)kg = 0.5kg.

c =4200 J/kg°C

Δt = 35°C - 20°C= 15°C

<u>Calculation</u>

Q = mcΔt

Q = 0.5kg x 4200J/kg°C x 15°C
Q = <u>31 500J</u>

Heating Up 2: Specific *Latent* Heat.

Specific ***Heat Capacity*** is used when a substance is heating up (it's temperature is increasing. If it's changing state (melting, or, boiling), we need to use Specific ***Latent Heat.***

$$Q = mL$$

Where **Q** is energy taken in (or given out)
m is the mass of the substance that changes state
L is the Specific Latent Heat.

Melting or Boiling?

A substance can ***melt*** (solid to liquid) or ***boil/evaporate*** (liquid to gas). The energy needed per kilogram is different for each. So ***make sure you know which change is happening and use the correct data!***

Specific latent heat of ***fusion:*** When a substance melts (or freezes)

Specific latent heat of ***vaporisation:*** When a substance boils (or condenses)

Example: Melting.

1 500g of ice melts. Calculate the total energy required. *The specific latent heat of fusion for ice is 334kJ.kg.*

Data m = 1 500g = 1.5kg
L = 334kJ/kg = 334 000J/kg

Calculation

Q = mL

Q = 1.5kg x 334 000J/kg
Q = 501 000J

Example: Boiling.

1.5kg of water is heated up until it has completely evaporated. Calculate the total energy needed to go from water at 100°C to steam at 100°C.

Data m = 1.5kg
L = 2265kJ/kg = 2 265 000J/kg

Calculation

Q = mL

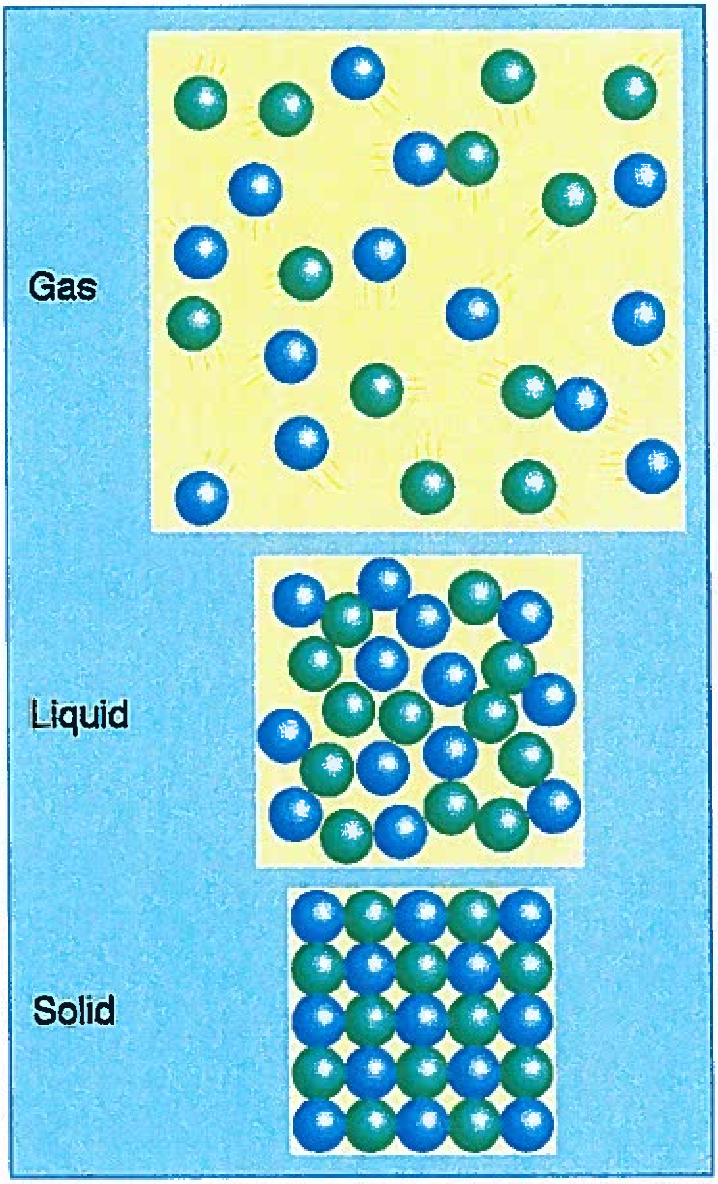
Q = 1.5kg x 2 265 000J/kg
Q = 3 397 500J

Remember: ***Substances absorb heat energy as their temperature increases, as they melt and as they boil/evaporate.***

BUT, substances lose heat energy as their temperature decreases, as they condense (change from gas to liquid), or, solidify.

Particles and Internal Energy:

Melting: No temperature change.
Energy is used up weakening the bonds between the particles



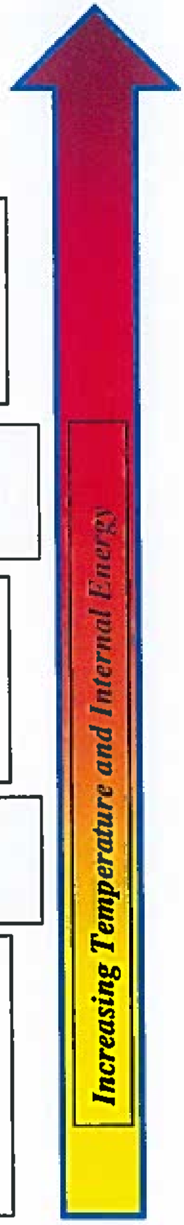
In a gas, all the bonds between particles have been broken. Particles move at high speed at random. The higher the temperature, the faster the particles move (greater kinetic energy).

Boiling: No temperature change. Energy is used up breaking bonds between the particles.

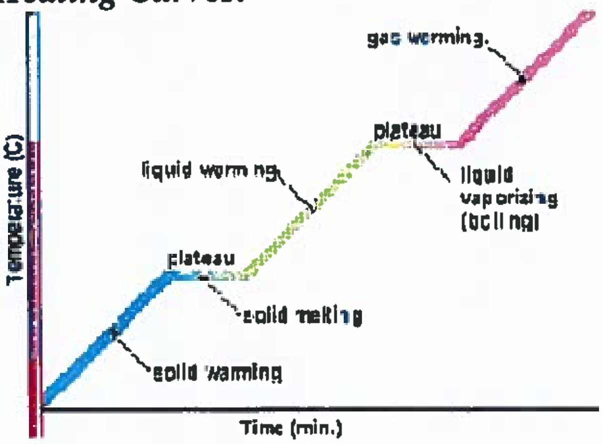
In a liquid, there are still strong inter particle bonds, but the particles can flow past each other. As temperature increases the particles move faster (greater kinetic energy).

Melting: No temperature change. Energy is used up weakening the bonds between the particles

In a solid, the particles vibrate about a fixed point. As energy is put into the substance, the particles vibrate more so they take up more space. The individual particles do not expand, but the total volume of the solid increases. This means its density decreases.



Heating Curves:



A graph can be drawn to show how the temperature of a substance changes as it is heated.
There is no change in temperature as the substance changes state from solid to liquid or liquid to gas.

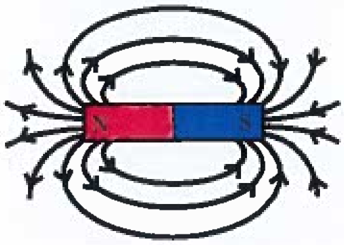
A *Cooling Curve* graph can also be shown to show what happens to a substance that starts off as a hot gas and is allowed to cool.
There will be no temperature change shown as the substance condenses (gas to liquid) or solidifies (liquid to solid).
Remember **–** with a cooling curve the temperature will stop falling when the substance reaches room temperature.

Unit 1 - Electromagnetism

Magnetic fields

A magnetic field is a region where magnetic materials feel a force. Magnetic fields are created by magnets, or current flowing in a wire. Here are some magnetic fields you should know about :

A bar magnet



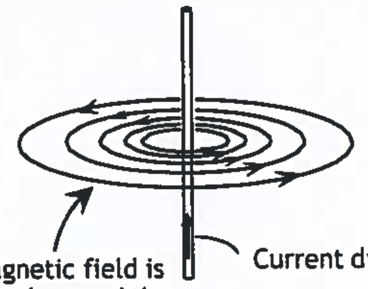
Notice that the magnetic field lines show three things :

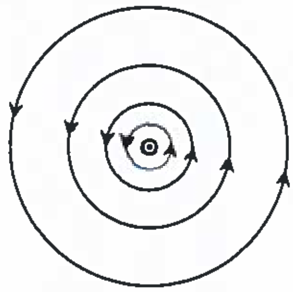
1) **The shape of the field**

2) **The direction** - out of the North pole; into the South.

3) **The strength of the field** - the field is stronger where the lines are closer together.

A long, straight wire with a current flowing through it

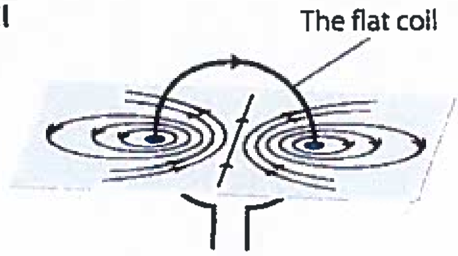




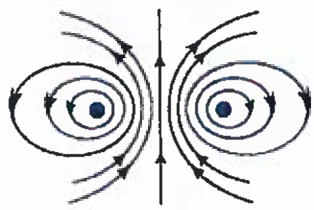
Plan view (bird's-eye)

Notice that the field lines get further apart the further they are from the wire, since the magnetic field is getting weaker.

A flat coil

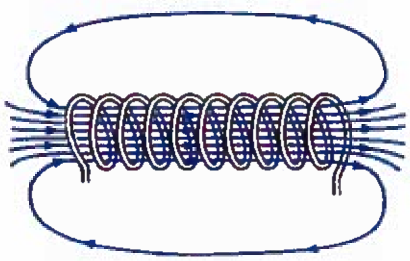


Magnetic field pattern generated by a flat coil



Magnetic field pattern generated by a flat coil (Plan view)

A long coil (solenoid)



Notice that the field lines **inside** the coil are almost straight and parallel - this shows the magnetic field has a constant strength in this region.

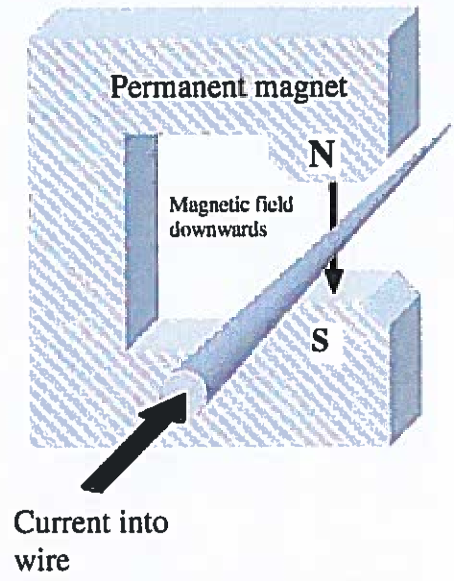
Also, notice that the shape is very similar to that of the magnetic field around a bar magnet.

The Motor Effect

We can use the magnetic effect of electricity to produce movement.

If a current-carrying wire is placed in the magnetic field of a permanent magnet, **two** magnetic fields will exist on top of each other - one due to the permanent magnet, and one from the electricity flowing in the wire.

This produces a **force** on the wire, in exactly the same way a force is produced between two magnets placed close together.



The size of the force on the wire can be increased by doing one of three things :

1. **Increasing the current**
2. **Increasing the magnetic field strength**
3. **Increasing the number of wires in the field**

The force produced on a wire can be used to create movement (rotational), and is known as the 'Motor Effect'.

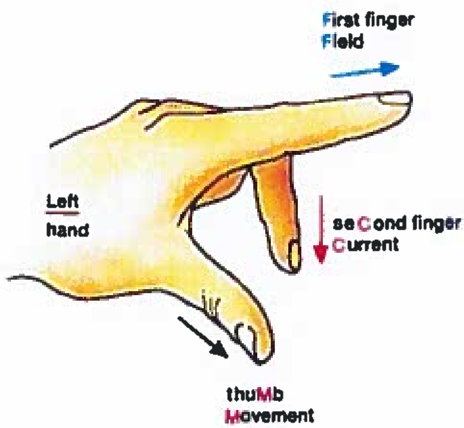
It's possible to predict the direction of the force by using **Fleming's LEFT hand rule.**

If the thumb and first two fingers of the left hand are placed at right angles to each other as shown then . . . .

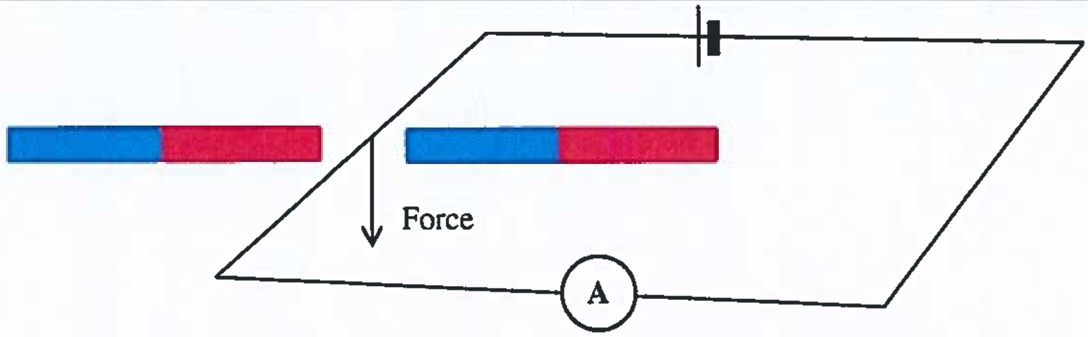
the First finger is in the direction of the Field

the seCond finger is in the direction of the Current

and the thuMb is in the direction of Motion.



The Motor Effect ~ Calculating the force. (Higher Tier)



A current carrying wire experiences a force if it is in a magnetic field.
Fleming's Left Hand Rule can be used to work out the direction of the force.

But how big will the force be?

$$F = BIl$$

Or

Force = Magnetic Field Strength x Current x length of wire in the magnetic field.

F (Force) is measured in Newtons (N).

B (Magnetic Field Strength) is measured in Tesla (T).

I (Current) is measured in Amps (A).

Length (l) is measured in metres (m).

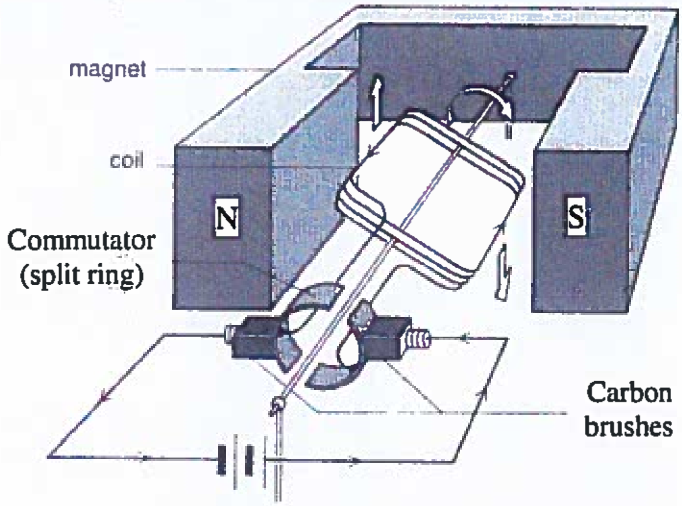
The idea of magnetic field strength (B) is new to you and will only be used to calculate force. Don't worry about using it for anything else. You will be given any data you need.

Guess where the name of this electric car came from!

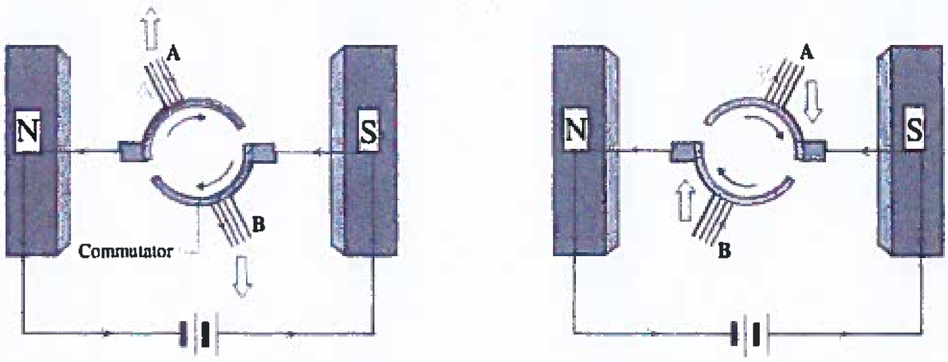
The Motor

When current passes through the coil, a force acts upwards on one side of the coil, and downwards on the other side.

The overall effect of these forces is to make the coil turn on its axis.

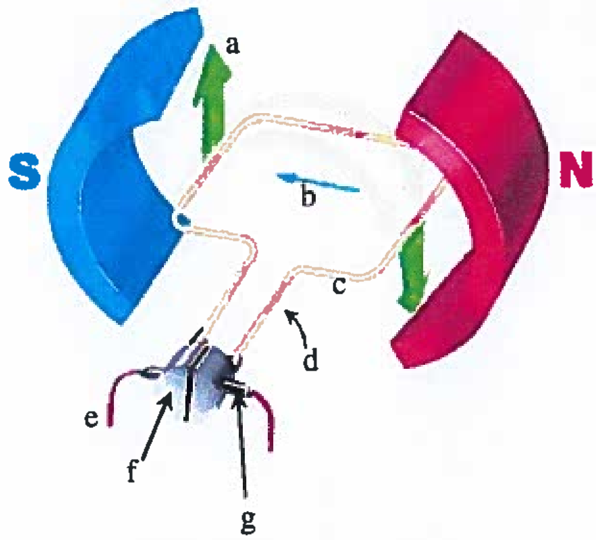


The split ring commutator ensures that the force on any wire on the left hand side of the motor is always directed upwards, and that the force on the right hand side is always downwards. This makes sure that the coil turns continuously in one direction.



Question : Match each label (1→7) to the correct part (a→g) for the simple dc electric motor below :

1. Commutator (Split rings)
2. Voltage in
3. Magnetic field
4. Motion / Force
5. Coil
6. Electric current
7. Brushes

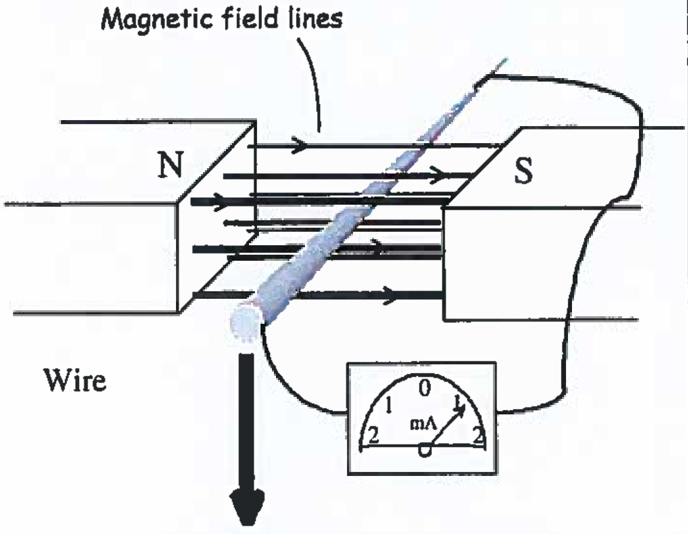


Answer : 1=f, 2=e, 3=b, 4=a, 5=c, 6=d, 7=g

Electromagnetic Induction

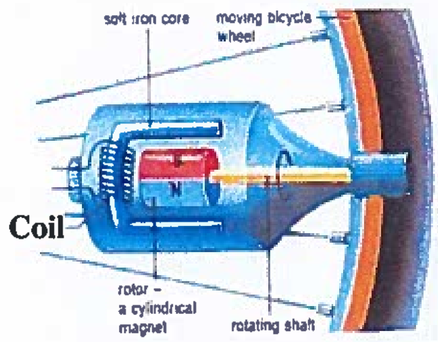
If a metal wire is forced to move through a magnetic field (or a magnetic field is moved through a wire), a **voltage** is produced across the wire.
If this wire is part of a complete circuit, this voltage will push a current around the circiut.

Another way of saying this would be :
"electricity is induced (created) when a wire CUTS through magnetic field lines".

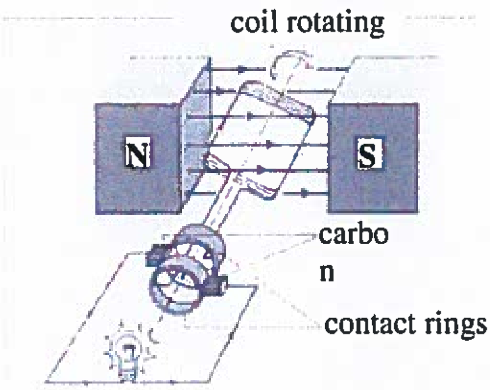


Wire is forced downwards, cutting through the field.

As you can see in the diagrams below, it makes no difference whether it's a magnet turning inside a coil, or a coil turning inside a magnetic field, the effect is the same - electricity is induced in the coil.

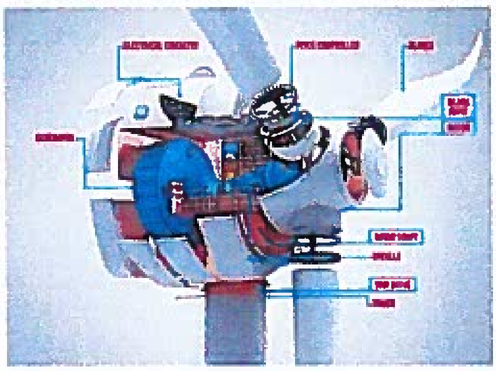


A 'dynamo' on a bicycle wheel

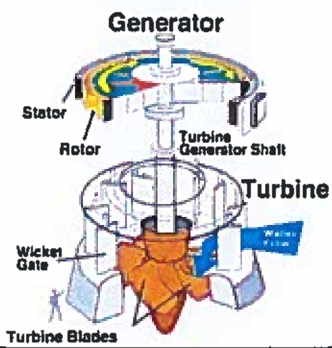


A small generator, e.g. a wind up torch

Generators are a crucial part of all power stations (except for solar PV). Shown below is a wind turbine - the generator can be seen at the back.



Here's a generator from a hydroelectric power station ➔



Generators

The output voltage/current is **proportional** (doubling one variable doubles the voltage/current) to :

1. **the speed of rotation**
2. **the number of turns on the coil**

and increases if the **magnetic field strength** increases.

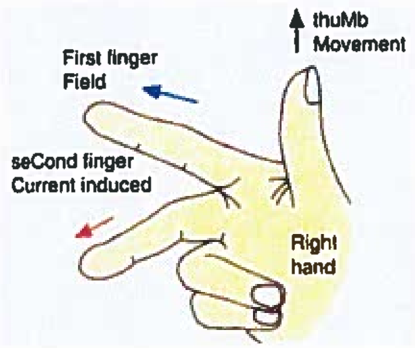
The direction of the induced current can be predicted by using Fleming's **RIGHT** hand rule.

If the thumb and first two fingers of the right hand are placed at right angles to each other as shown then,

the First finger is in the direction of the Field

the thuMb is in the direction of Motion

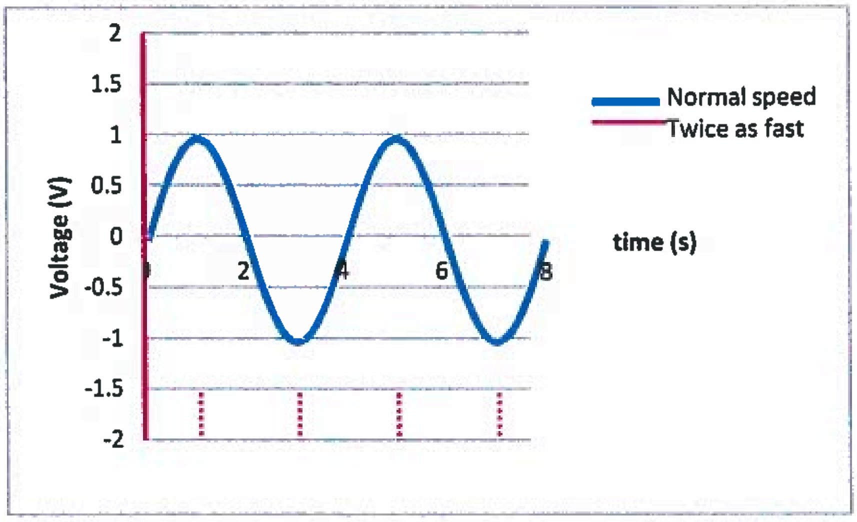
and the seCond finger is in the direction of the Current



What type of output voltage/current is produced by a generator ?

Usually, the circular movement that occurs in generators produces an alternating voltage or current. 'Alternating' means that the current/voltage direction changes regularly. For most generators the circular movement also means that the output current is constantly changing in size - this is explained on the next page.

Here's a graph showing a typical output from a generator :

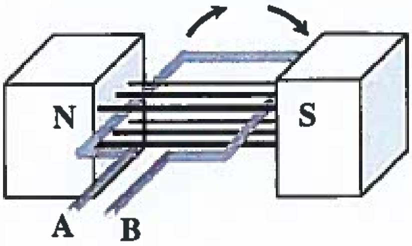


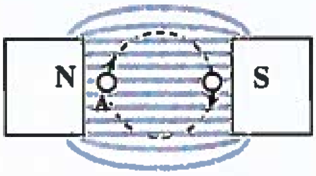
Notice the effect of **doubling** the speed of rotation of the generator.

One 'rotation' or cycle takes 2 seconds (rather than 4s).

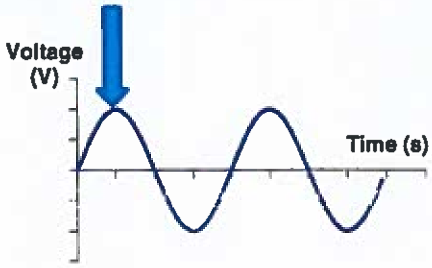
Also, the peak voltage is now **twice** as large since the coil in the generator is breaking through magnetic field **twice** as quickly - see point 1 at the top of the page !

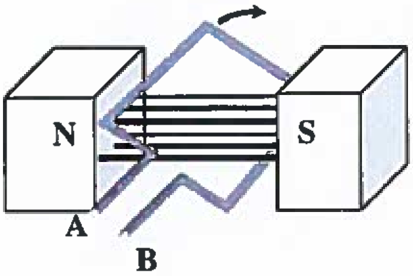
Understanding the shape of the output voltage of a generator

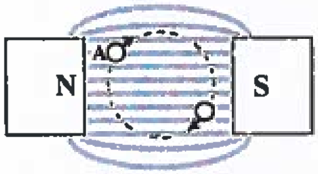




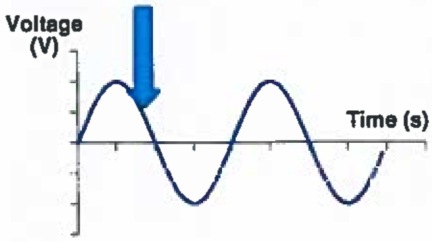
The coil is cutting through magnetic field lines at its greatest rate, and so this is when the maximum voltage/current is produced.

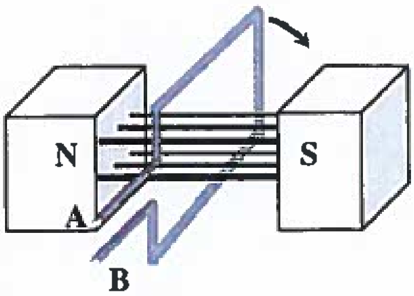


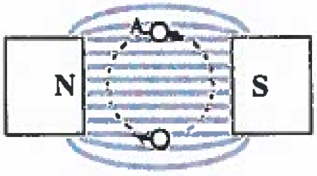




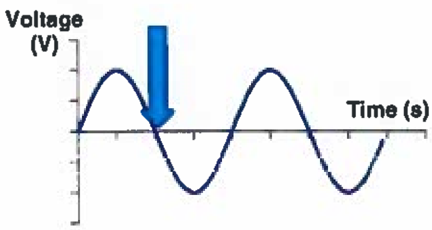
Side "A" of the coil is still cutting upwards through magnetic field lines, and so the voltage is still positive. However, because of the angle, the coil isn't cutting the lines as quickly as before, and so there's less voltage.

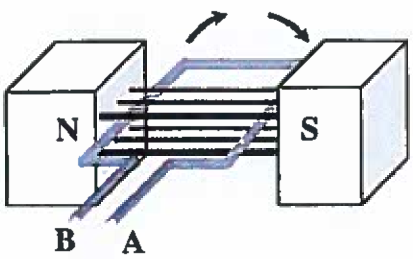


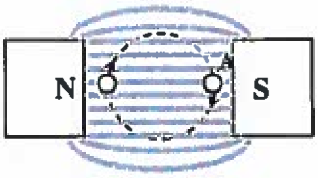




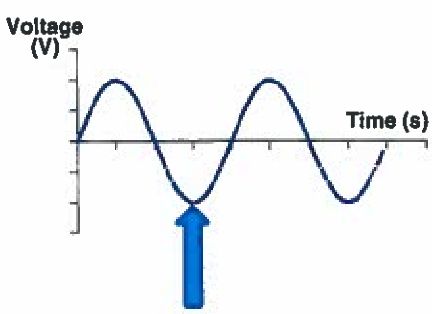
The coil is not cutting any field lines - its just moving along with them in the North-South direction. This means that NO voltage is produced.







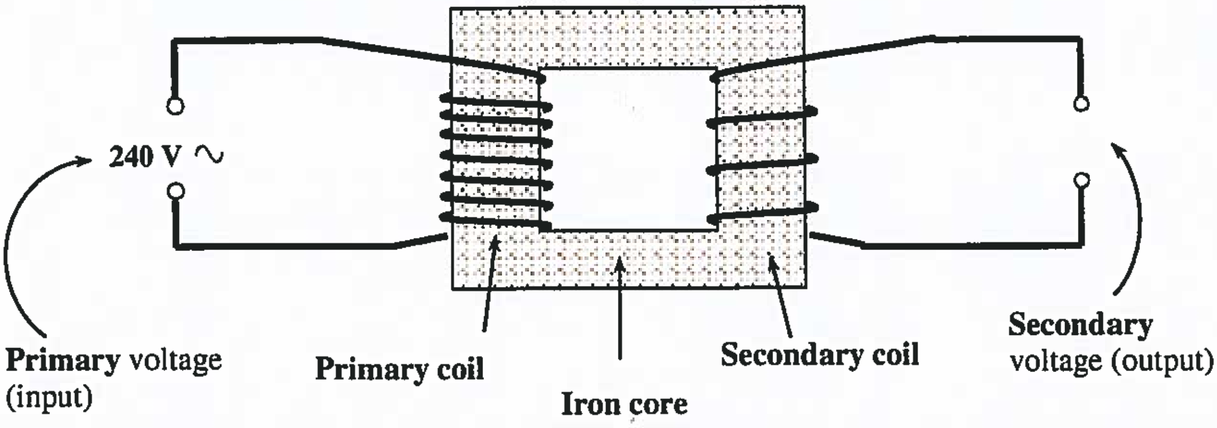
Once again lines are being cut at maximum rate, but side "A" of the coil is now cutting down through the magnetic field. This changes the direction of the voltage.



Using Induction - TRANSFORMERS

A transformer is a device that makes use of the fact that electricity can be created (induced) by a **changing magnetic field**. Transformers are used to increase (step-up) or decrease (step-down) the voltage.

Here's a diagram of a transformer where two separate coils have been wound around two sides of the same piece of solid iron 'core':



← Here's a large transformer in the National grid ......

...... and here's a small transformer - a phone charger →

The explanation for how electricity is created in the secondary coil could be asked for in a "QWC"-style examination question. Here's an example of a well-structured answer :

> The alternating current in the primary coil creates a changing magnetic field around it. Iron is a magnetic material, and so easily transmits this magnetic field to the secondary coil. The constantly changing magnetic field around the secondary coil induces a voltage in this coil.

Additionally, whether this output voltage is greater or lesser than the primary voltage depends on the amount of turns in the secondary coil as compared to the primary.

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

where
- V_1 = voltage across the primary coil
- V_2 = voltage across the secondary coil
- N_1 = number of turns on the primary coil
- N_2 = number of turns on the secondary coil

Example : *The input (primary) voltage of a phone charger is 240V (mains). The output needs to be 4.8 V. Calculate "N_2" (the number of turns on the secondary coil) if N_1 = 2000.*

$$N_2 = \frac{N_1 \times V_2}{V_1} = \frac{2000 \times 4.8}{240} = 40 \text{ turns}$$