Alun School

Physics GCSE Revision Materials

Unit 1

Topics:

This unit includes the following topics:

1.1 Electric circuits

1.2 Generating electricity

1.3 Making use of energy

1.4 Domestic electricity

1.5 Features of waves

Unit 1.1 – Electric Circuits

(a) the symbols of components (cell, switch, lamp, voltmeter, ammeter, resistor, variable resistor, fuse, LED, thermistor, LDR, diode) used in electrical circuits

(b) series circuits in which the current is the same throughout a circuit and voltages add up to the supply voltage; parallel circuits in which the voltage is the same across each branch and the sum of the currents in each branch is equal to the current in the supply

(c) voltmeters and ammeters to measure the voltage across and current in electrical components in electrical circuits

(d) circuits to investigate how current changes with voltage for a component e.g. for a resistor (or wire) at constant temperature, a filament lamp and a diode

(e) the significance of and the relationship between current, voltage and resistance, $I = \frac{V}{R}$

(f) how adding components in series increases total resistance in a circuit; adding components in parallel decreases total resistance in a circuit

(g) how to calculate total resistance and total current in a series circuit, **a parallel circuit and circuits consisting of combinations of series and parallel connections**;

$$R = R_1 + R_2; \qquad \mathbf{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}}$$

(h) power as energy transferred per unit time: $E = Pt$

(i) the power transferred using:

power = voltage × current $\quad P = VI$

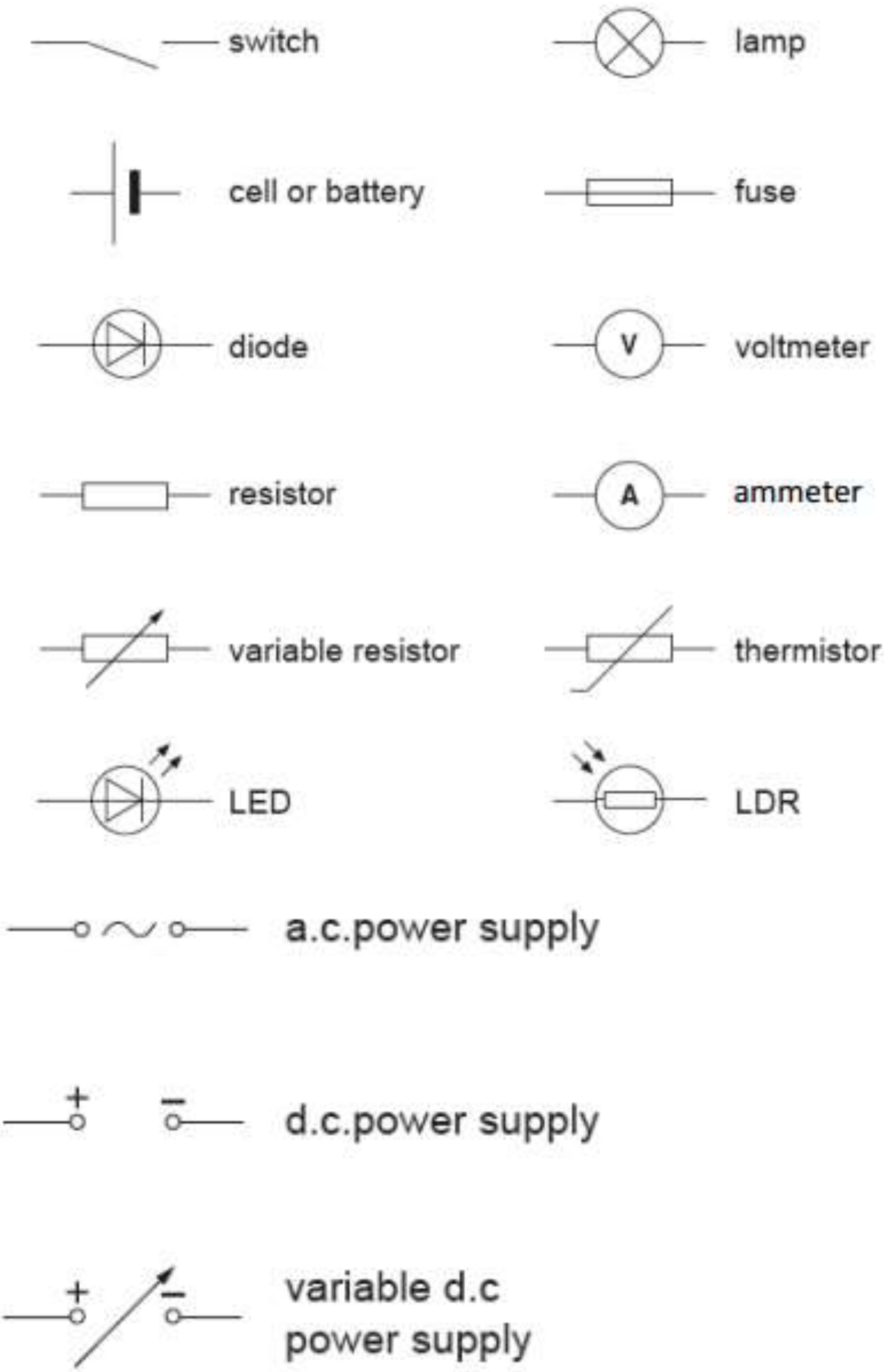
power = current² × resistance $\quad \mathbf{P = I^2 R}$

(j) explain the design and use of circuits to explore the variation of resistance – including for lamps, diodes, ntc thermistors and LDRs

SPECIFIED PRACTICAL WORK

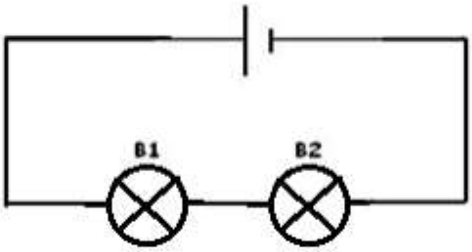
- Investigation of the current-voltage (I-V) characteristics for a component

Be able to draw circuit diagrams.

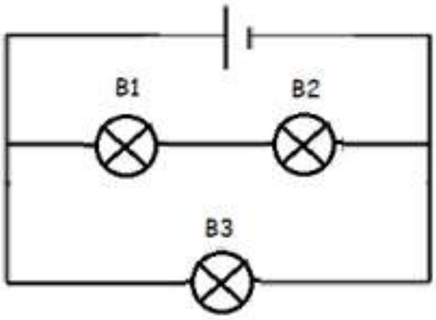


Series and Parallel circuits.

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

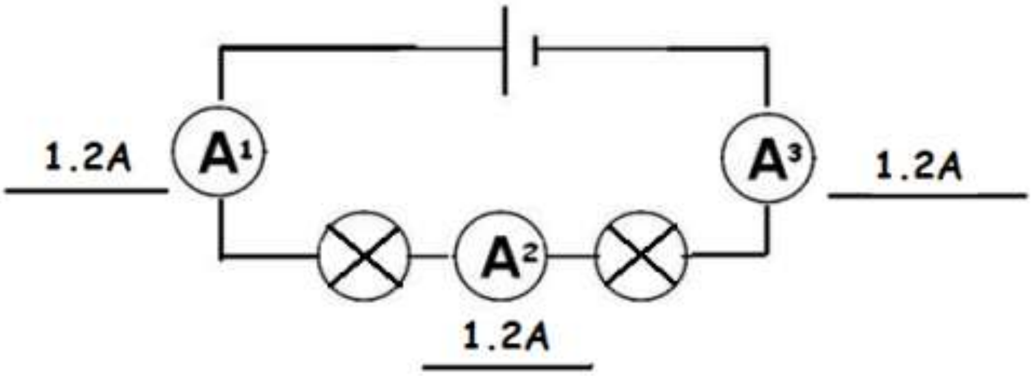


Parallel circuit: in a parallel circuit there is more than one path and the circuit is divided into branches. Bulbs B1 and B2 are in series but B3 is in parallel with them. If bulb B3 breaks then B1 and B2 will continue to work.



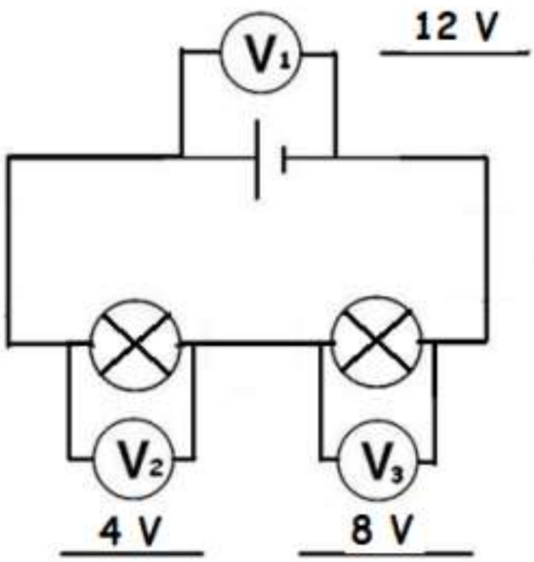
Measuring current and voltage in circuits.

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



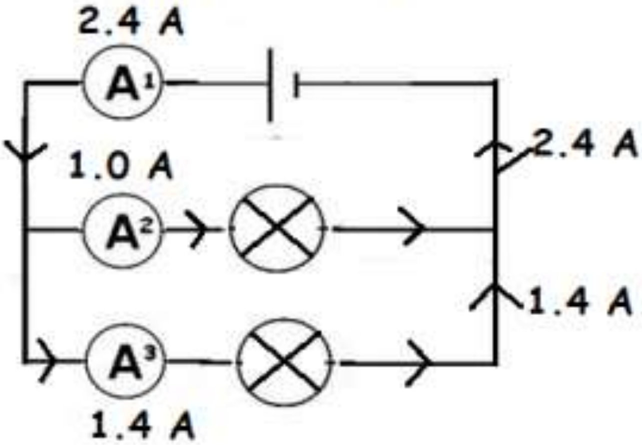
The value of the current is the same at all points ($A_1 = A_2 = A_3$) in the circuit since there is only one path for the current to flow.

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



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

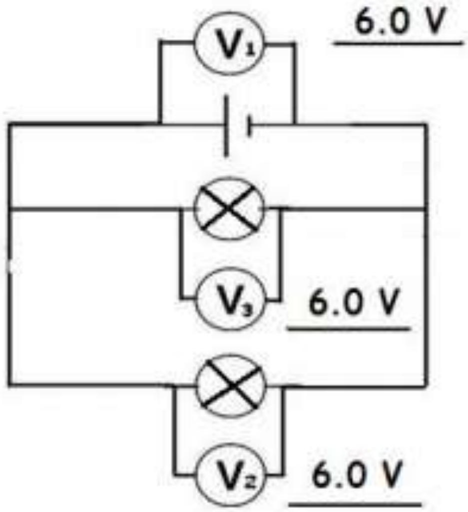
Current in parallel circuits: the ammeter in this series circuit is connected in series.



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

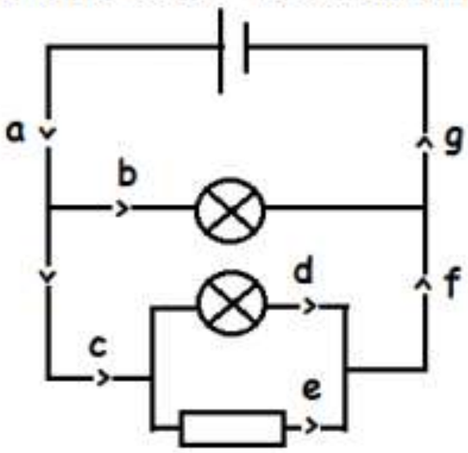
Voltage in parallel circuit: the voltage across all components in parallel is the same.

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



Predicting current values.

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



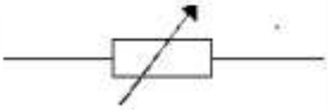
Point	Current (A)
a	3.6
b	2.0
c	
d	1.2
e	
f	
g	

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

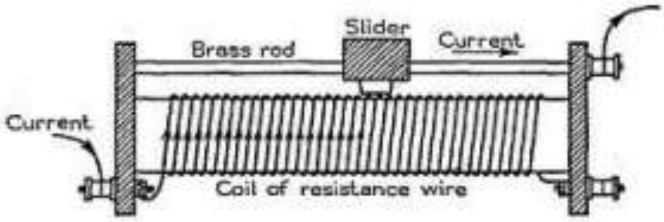
Variable resistors (controlling the current).

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

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



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

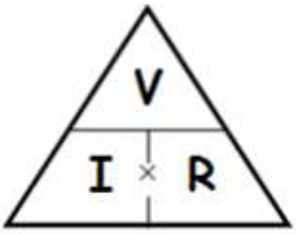


Wire-wound rheostat

Ohm's law

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

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.

$V = 1.8 \times 15 = 27$ V

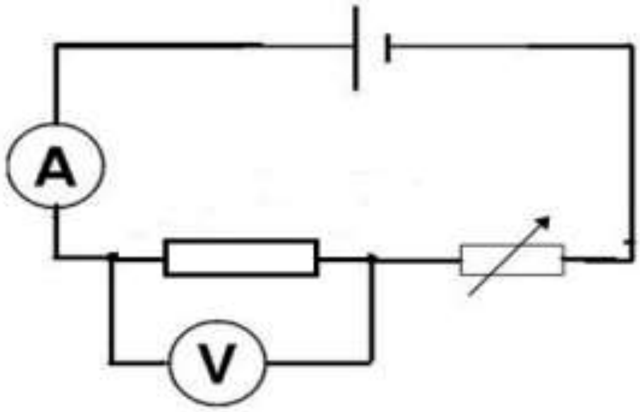
Q1. Calculate the current through a 2kΩ resistor when there is a voltage of 230V across it.

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.

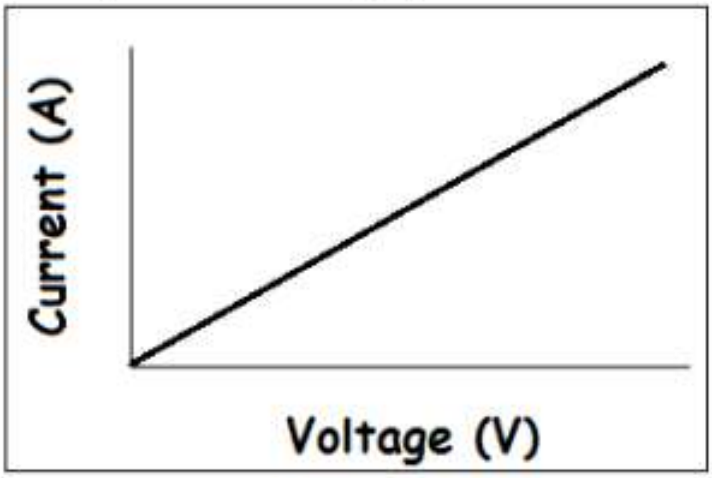
Answers: Q1 = 0.115 A , Q2 = 57.5 Ω

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***.

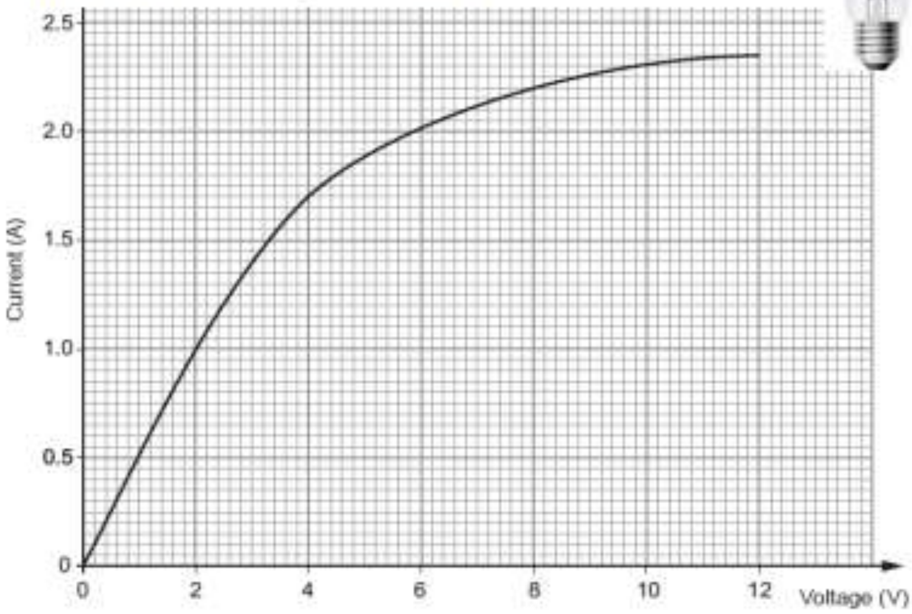
Changing resistance

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

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) $R = \frac{12.0}{2.35} = 5.11\ \Omega$

Resistance graphs

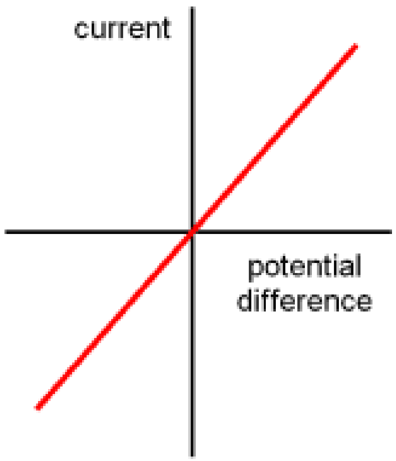
Current-potential difference graphs

Take a graph where the current flow is shown on the vertical axis and the potential difference is shown on the horizontal axis. This shows that as the current changes in a component, so does the potential difference.

You should be able to recognise these graphs for resistors at constant temperature, for *filament lamps*, and for diodes.

Resistor at constant temperature

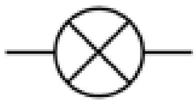
The current flowing through a resistor at a constant temperature is directly proportional to the potential difference across it. A component that gives a graph like the one to the right is said to follow *Ohm's Law*.



A graph with current on the y axis and voltage on the x axis. A diagonal line goes through the graph at 45 degrees

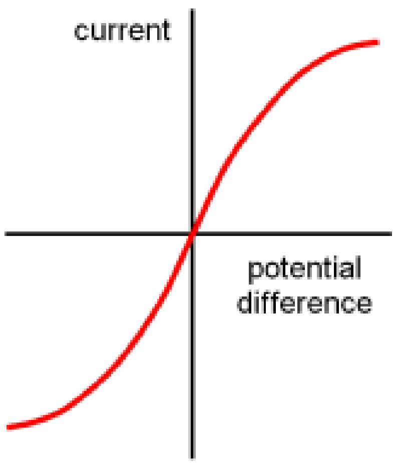
The filament lamp

The filament lamp is a common type of light bulb. It contains a thin coil of wire called the filament. This heats up when an electric current passes through it and produces light as a result.



Lamp

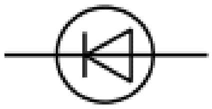
The filament lamp does not follow Ohm's Law. Its resistance increases as the temperature of its filament increases. So the current flowing through a filament lamp is not directly proportional to the voltage across it. This is the graph of current against voltage for a filament lamp.



The diode

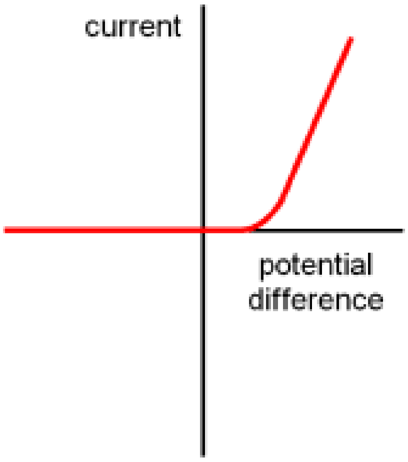
You should be able to recognise the graph of current against voltage for a diode.

Diodes are electronic components that can be used to regulate the potential difference in circuits and to make logic gates. Light-emitting diodes (LEDs) give off light and are often used for indicator lights in electrical equipment such as computers and television sets.



Diode

The diode has a very high resistance in one direction. This means that current can only flow in the other direction. This is the graph of current against potential difference for a diode.



Series and parallel circuits

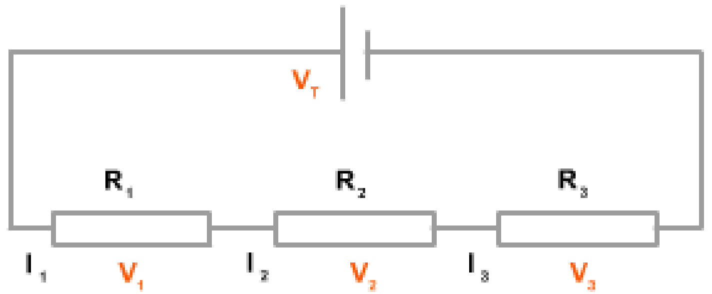
Resistor in series

When resistors are connected in series, the *current* through each resistor is the same. In other words, the current is the same at all points in a series circuit.

When resistors are connected in series, the total potential difference across all the resistors is equal to the sum of the potential differences across each resistor.

In other words, the potential differences around the circuit add up to the potential difference of the supply.

The total resistance of a number of resistors in series is equal to the sum of all the individual resistances.



In the circuit above, the following applies

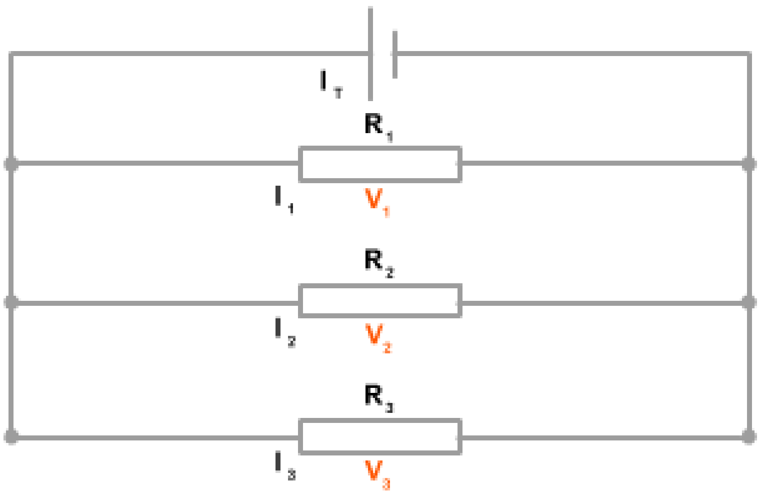
- $I_1 = I_2 = I_3$
- $V_T = V_1 + V_2 + V_3$

And so, therefore, $\mathbf{R}_T = \mathbf{R}_1 + \mathbf{R}_2 + \mathbf{R}_3$

Resistors in parallel

When resistors are connected in parallel, the supply current is equal to the sum of the currents through each resistor. In other words the currents in the branches of a parallel circuit add up to the supply current.

When resistors are connected in parallel, they have the same potential difference across them. In other words, any components in parallel have the same potential difference across them.



For the circuit above, the formula for finding the total resistance of resistors in parallel is $1/R_T = 1/R_1 + 1/R_2 + 1/R_3$

- $I_T = I_1 + I_2 + I_3$
- $V_1 = V_2 = V_3$

And so $\mathbf{1/R_T = 1/R_1 + 1/R_2 + 1/R_3}$

Electrical Power.

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

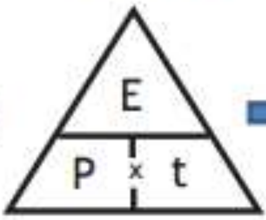
Power is measured in WATT, W. Equation, **Power = Voltage x current, P = V x I**

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

Power 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 ?

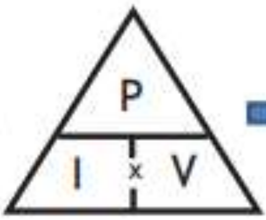
Answer : E = P x t = 3000 x (3x60) = 540 000 J

Look !!! The time must be in **seconds**, 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)

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 x I V = I x R

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

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

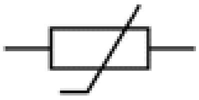
Thermistors and LDRs

You should be able to recognise the circuit symbols for the thermistor and the LDR (light-dependent resistor), and know how the resistance of these components can be changed.

The thermistor

Thermistors are used as temperature sensors - for example, in fire alarms. Their resistance decreases as the temperature increases:

- At low temperatures, the resistance of a thermistor is high and little current can flow through them.
- At high temperatures, the resistance of a thermistor is low and more current can flow through them.

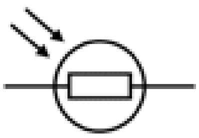


Thermistor

The LDR

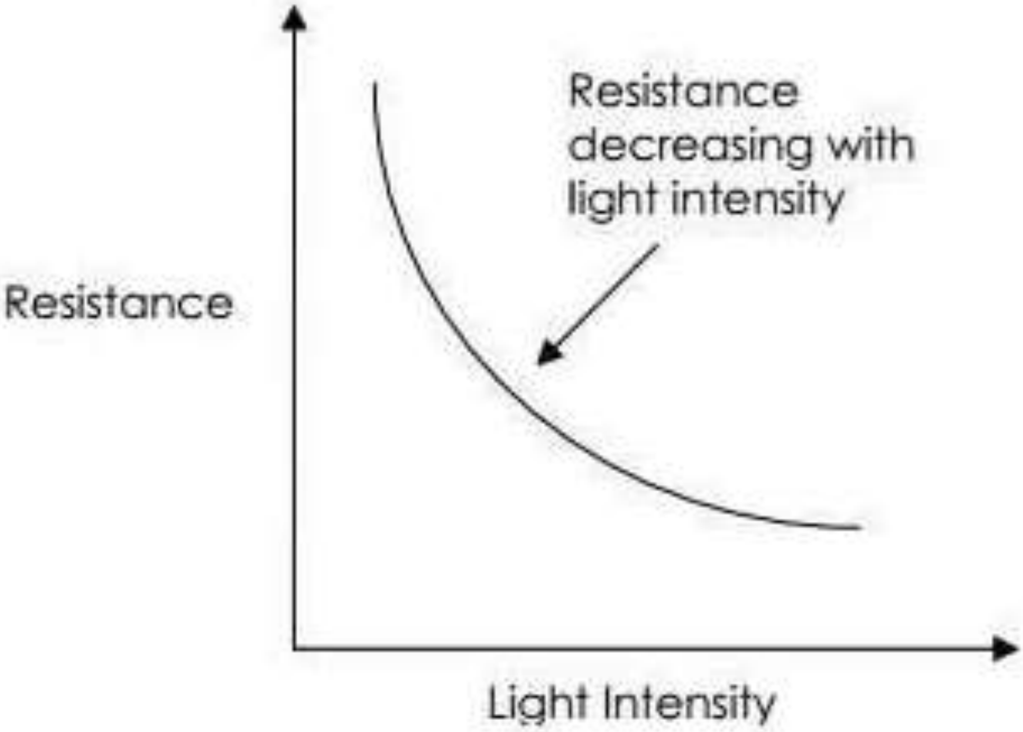
LDRs (light-dependent resistors) are used to detect light levels, for example, in automatic security lights. Their resistance decreases as the light intensity increases:

- In the dark and at low light levels, the resistance of an LDR is high and little current can flow through it.
- In bright light, the resistance of an LDR is low and more current can flow through it.

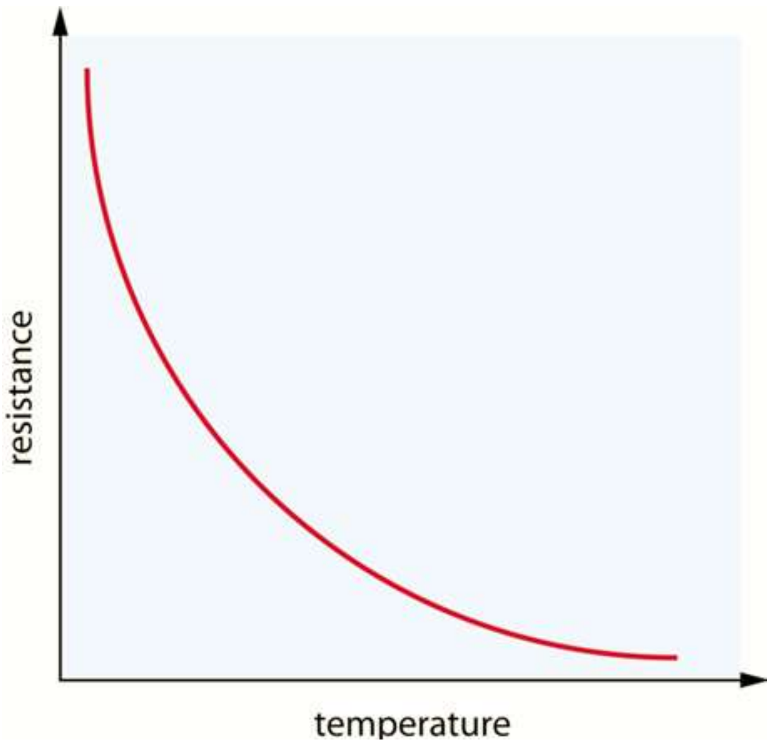


Light dependent resistor (LDR)

LDR graph



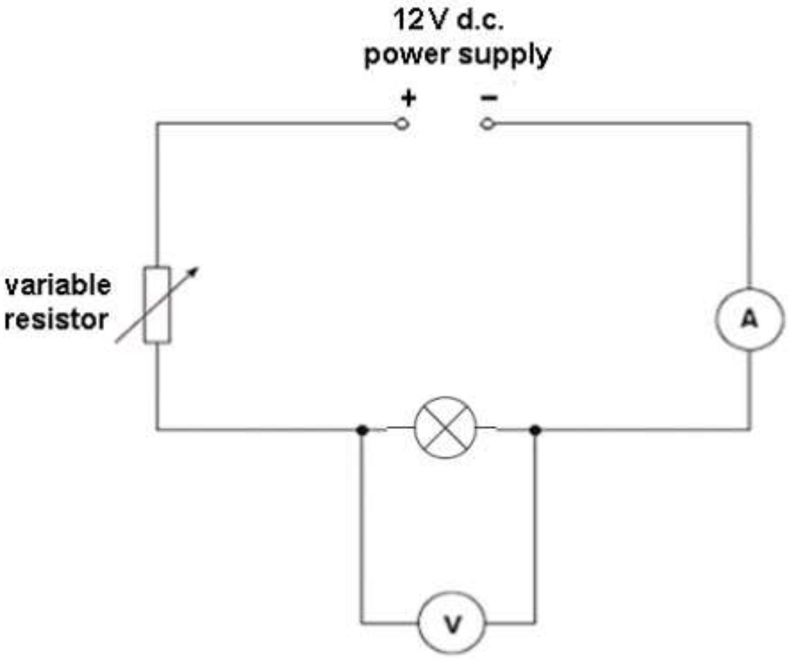
Thermistor graph



Apparatus

12 V filament lamp
voltmeter ±0.01 V
ammeter ±0.01 A
connecting leads
12 V d.c. power supply
variable resistor

Diagram of Apparatus



Method

1. Connect the circuit as shown in the diagram.
2. Adjust the variable resistor until the voltmeter reads 1 V.
3. Record the readings of voltage and current.
4. Adjust the variable resistor to increase the voltmeter reading to 2 V.
5. Record the readings of voltage and current.
6. Repeat steps 4 to 5, increasing the voltage by 1 V each time, until the voltmeter reads 12 V.

Analysis

1. Plot a graph of current (y-axis) vs voltage (x-axis).

Risk Assessment

Hazard	Risk	Control measure
Hot lamps can burn	Burning skin on hot lamps	Allow lamp to cool before touching them.

Unit 1.2 – Generating Electricity

(a) the advantages and disadvantages of renewable energy technologies (e.g. hydroelectric, wind power, wave power, tidal power, waste, crops, solar and wood) for generating electricity on a national scale using secondary information

(b) the advantages and disadvantages of non-renewable energy technologies (fossil fuels and nuclear) for generating electricity

(c) the processes involved in generating electricity in a fuel based power station

(d) Sankey diagrams to show energy transfers; energy efficiency in terms of input energy and energy usefully transferred in a range of contexts including electrical power generation and transmission:

$$\%\text{ efficiency} = \frac{\text{energy [or power] usefully transferred}}{\text{total energy [or power] supplied}} \times 100$$

(e) the need for the National Grid as an electricity distribution system including monitoring power use and responding to changing demand

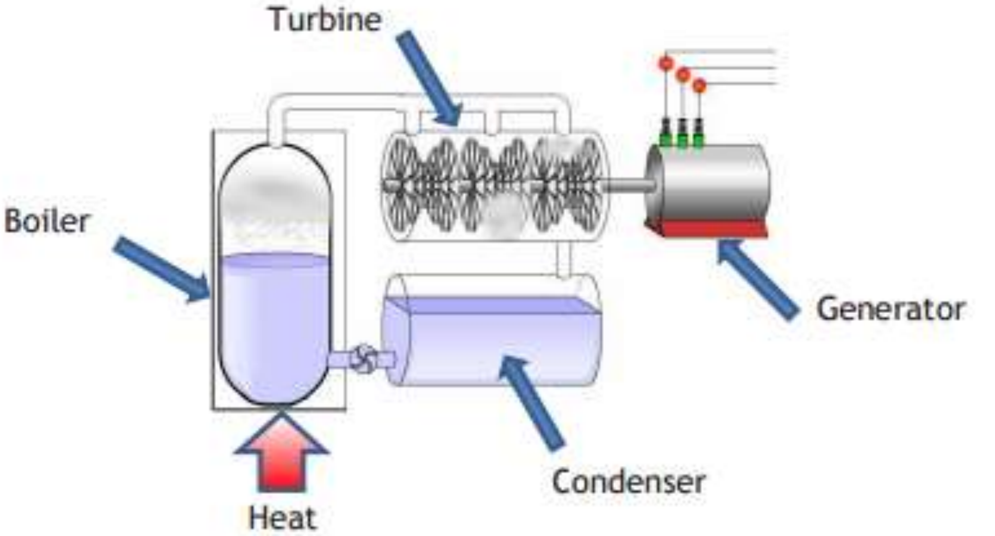
(f) advantages and disadvantages of using different voltages of electricity at different points in the National Grid to include transmission of electricity and use in the home, selecting and using the equation:

power = voltage × current; $P = VI$

(g) the use of step-up and step-down transformers used in the transmission of electricity from the power station to the user in qualitative terms (they should be treated as voltage changers without any reference to how they perform this function)

(h) efficiency, reliability, carbon footprint and output to compare different types of power stations in the UK including those fuelled by fossil fuels, nuclear fuel and renewable sources of energy

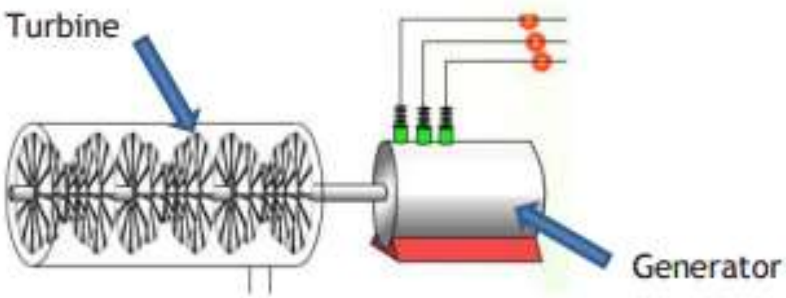
1. Shown below is a typical set-up for most power stations. The fuel is used to provide heat energy to water in a boiler. The water changes to steam which turns the blades of a turbine. The turbine is connected to a generator which then produces electricity.



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.**

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

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.*

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.

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

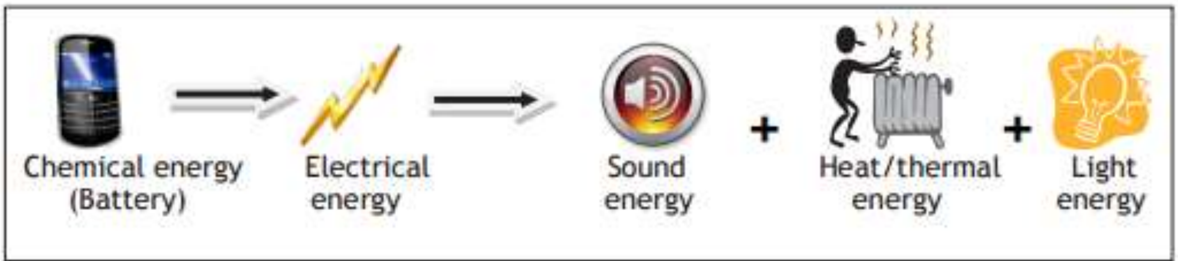
You will <u>not</u> be expected to remember data about different energy sources, only use what is given in the exam question.

See the example on the next page.

Energy Transfer

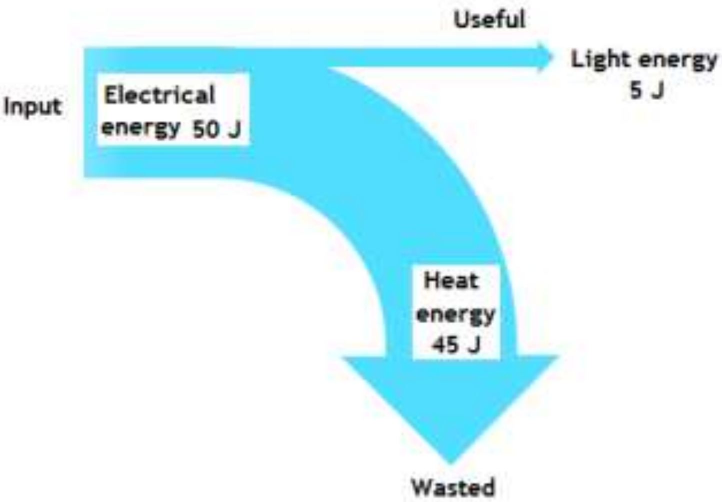
Type of energy	Example
Electrical	Into hairdryer.
Heat	Cooker.
Kinetic	Moving energy - car.
Sound energy	Speaker
Light energy	An object which emits light - LCD screen.
Chemical energy	Stored in food/battery.
Gravitational potential energy	Increases with height above ground - pump storage station.
Elastic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

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

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.

Transmitting electricity

There are 2 major problems with getting electricity from the power stations to our homes, schools, industries etc :

1. Heat energy is wasted in the cables

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

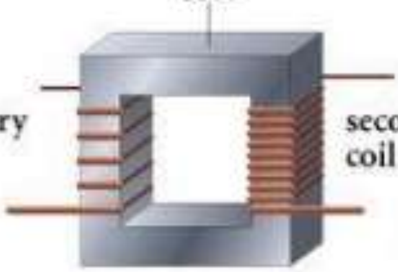
Info. ! ***How much electricity flows in a wire is known as electrical <u>current.</u>***

1. Heat energy is wasted in the cables

Typically, power stations produce electricity with a total current of about 10,000 Amps.
This is a **very** large current, and will cause a lot of heat to be produced in all the wires/cables carrying the electricity around the country !

If nothing were done, there simply wouldn't be enough electrical energy left to work all our devices in our homes.

It's the flow of electricity through wires, i.e. the **<u>current</u>**, that produces heat. So, if we want to reduce the heat produced in wires, we need to keep the current to a minimum. This is how it's done :



A step-up transformer !

Higher voltage → ***Lower current*** → ***Less heat wasted in the wires***

So, if the input voltage was, say, 20,000 Volts, and the step-up transformer increased this by a factor of 20 (20,000 x 20 = 400,000 V), then the current would reduce by a factor of 20.

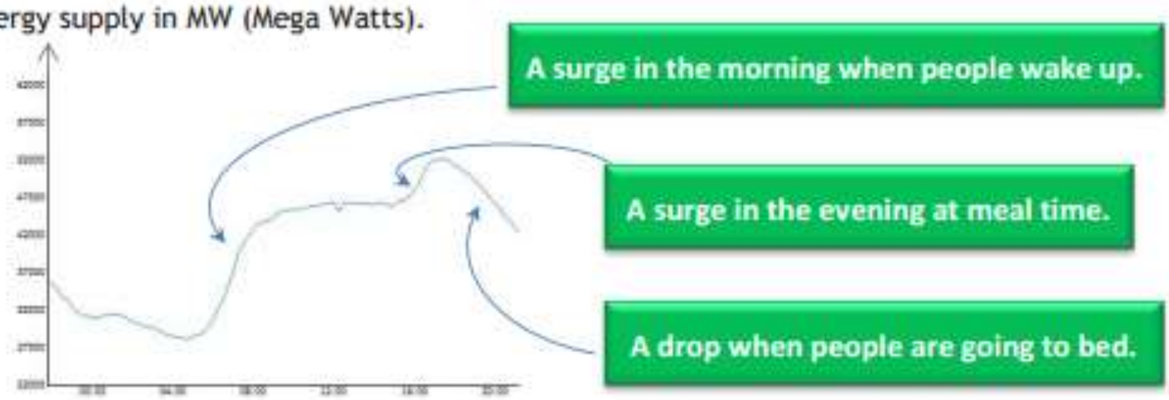
Note : The transformer creates no extra electrical power, so the input power is the same as the ouput power. The equation " Power = current x voltage " (P=IxV) can be used to calculate the effect on the current, when the voltage is changed.

Transmitting electricity

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 **supply** (how much is produced) and the **demand** (how much is needed).

Energy supply in MW (Mega Watts).

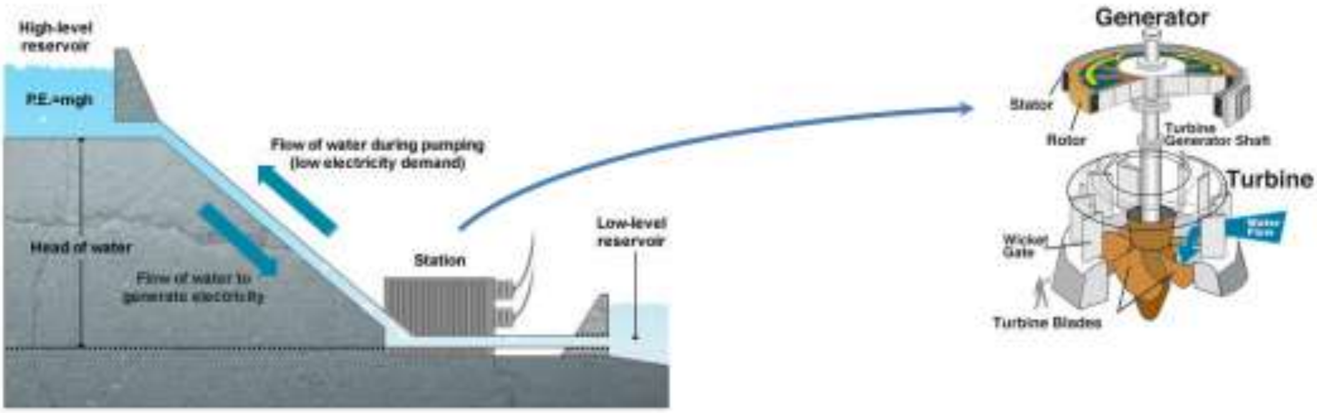


Note that "one-off" special events can cause surges too, as well as day-to-day events, e.g. a popular event at the Olympics; the FA cup final etc. The National Grid try to predict when these occur by looking at the TV listings !

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.

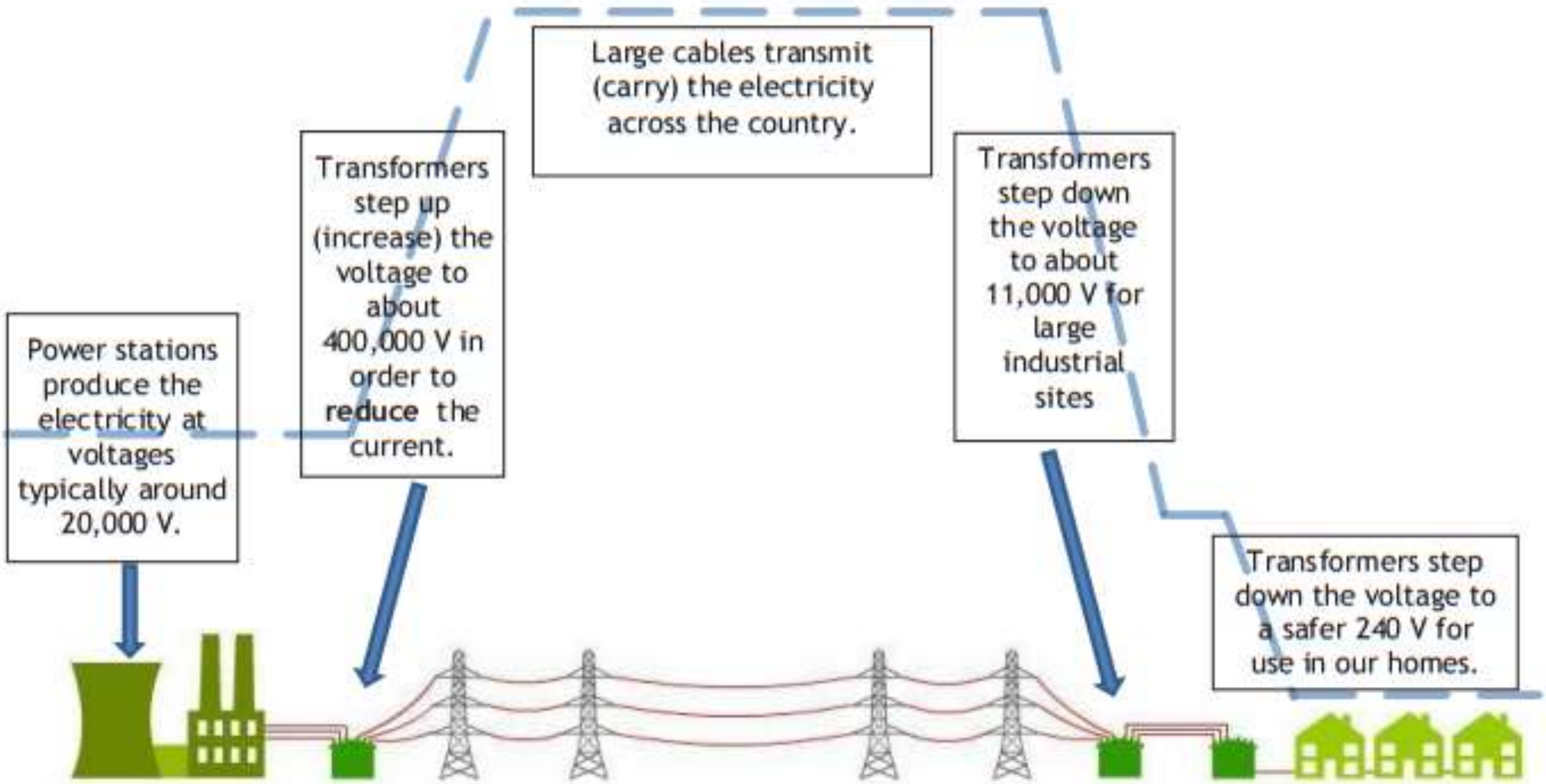
A fast-response hydroelectric power station (pump-storage)



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 **micro-generation** (e.g. solar panels on the roof; small wind turbines in the garden, etc.)



Transmitting electricity

Electricity is generated when a coil of wire moves in a magnetic field. This is the basis of electricity generators.

Most electricity is made in power stations by burning fuels. Transformers are used in the National Grid to reduce energy losses from the wires during transmission.

The National Grid and transformers

Transformers

A transformer is an electrical device that changes the voltage of an AC supply. A transformer changes a high-voltage supply into a low-voltage one, or vice versa.

- A transformer that increases the voltage is called a **step-up transformer**
- A transformer that decreases the voltage is called a **step-down transformer**

Step-down transformers are used in mains adapters and rechargers for mobile phones and CD players.

The National Grid

When a current flows through a wire, some energy is lost as heat. The higher the current, the more heat is lost. The National Grid transmits electricity at a low current to reduce these losses. This requires a high voltage.

Power stations produce electricity at 25,000V. Electricity is sent through the National Grid cables at 400,000V, 275,000V and 132,000V.

Step-up transformers at power stations produce the very high voltages needed to transmit electricity through the National Grid power lines. This is because high voltages improve efficiency by reducing heat loss in the power lines. But high voltages are too dangerous for use in the home, so step-down transformers are used locally to reduce the voltage to safe levels. Power lines and substations are potentially dangerous as an electric shock can kill someone who gets too close to such a high voltage supply.

Unit 1.3 – Making Use of Energy

(a) how temperature differences lead to the transfer of energy thermally by conduction, convection and radiation

(b) the equation: $\text{density} = \frac{\text{mass}}{\text{volume}}$ and explain the differences in density between the three states of matter in terms of the arrangements of the atoms or molecules

(c) **conduction using a model of molecular motion and account for the better conduction in metals by the presence of mobile electrons**

(d) **convection in liquids and gases in terms of molecular behaviour and variations in volume and density**

(e) how energy loss from houses can be restricted e.g. loft insulation, double glazing, cavity wall insulation and draught excluders

(f) the cost effectiveness and efficiency of different methods of reducing energy loss from the home, to compare their effectiveness; use data to compare the economics of domestic insulation techniques, including calculating the payback time; the economic and environmental issues surrounding controlling energy loss

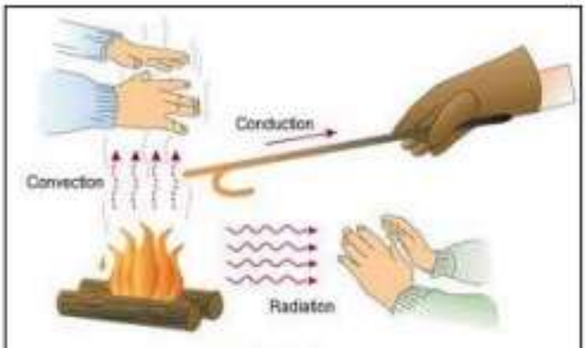
(g) how data can be obtained and used to investigate the cost of using a variety of energy sources for heating and transport

SPECIFIED PRACTICAL WORK

- Investigation of the methods of heat transfer
- Determination of the density of liquids and solids (regular and irregular)

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.



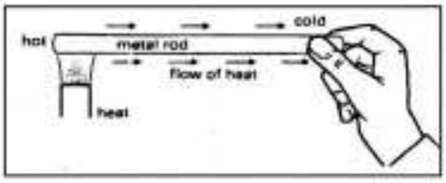
www.beodom.com

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:

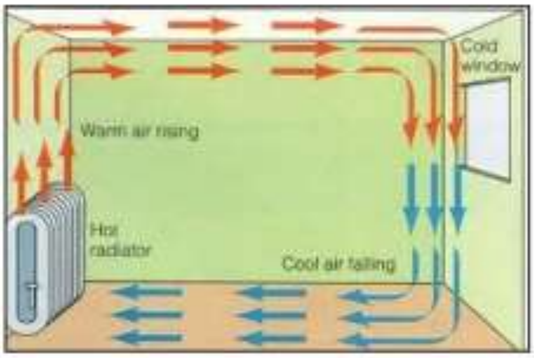
1. When gas/liquid heated.

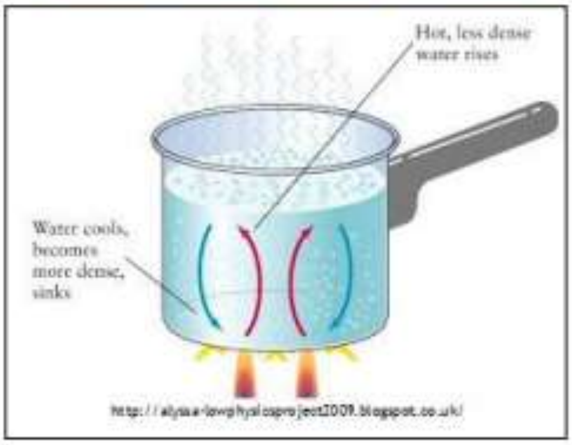
2. The particles speed up

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

4. Density decreases and so gas/liquid rises.

5. Colder, denser gas/liquid falls.





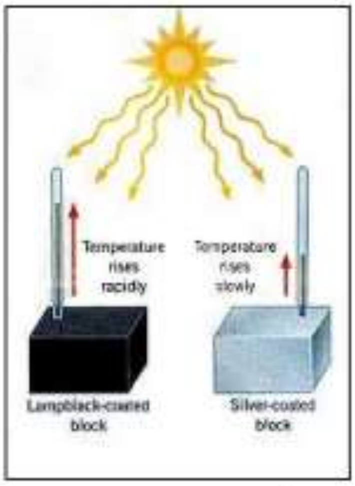
Some materials like foam trap air, which reduces the convection current. This reduces heat loss/transfer through convection.

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.

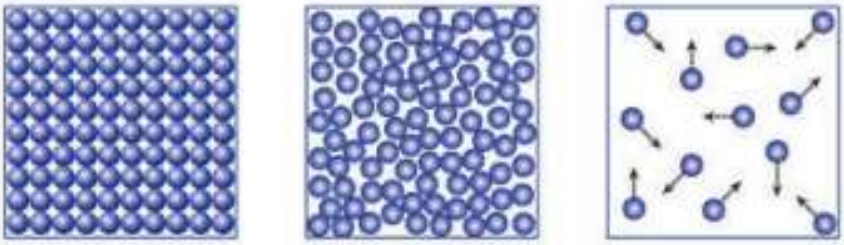


Dull Black	Shiny Black	Colours (dark --> Light)	White	Silver
Best Emitter/ Absorber	→	→	→	**Poorest Emitter/ Absorber**

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:



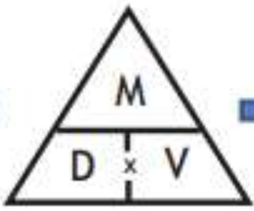
Solid Liquid Gas

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/cm^3 (or 1000 kg/m^3).
Air has a density of about 0.0013 g/cm^3.

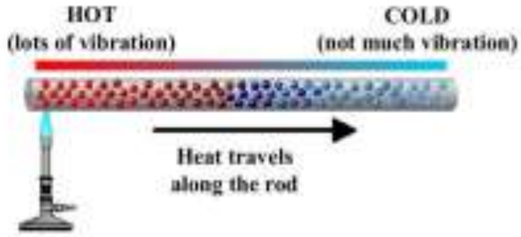
This is why a turbine driven by a certain volume of water is capable of generating more electricity than a turbine driven by the same volume of air.
1 m^3 of water weighs about 854 times the same amount of air.

Conduction & Convection

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.

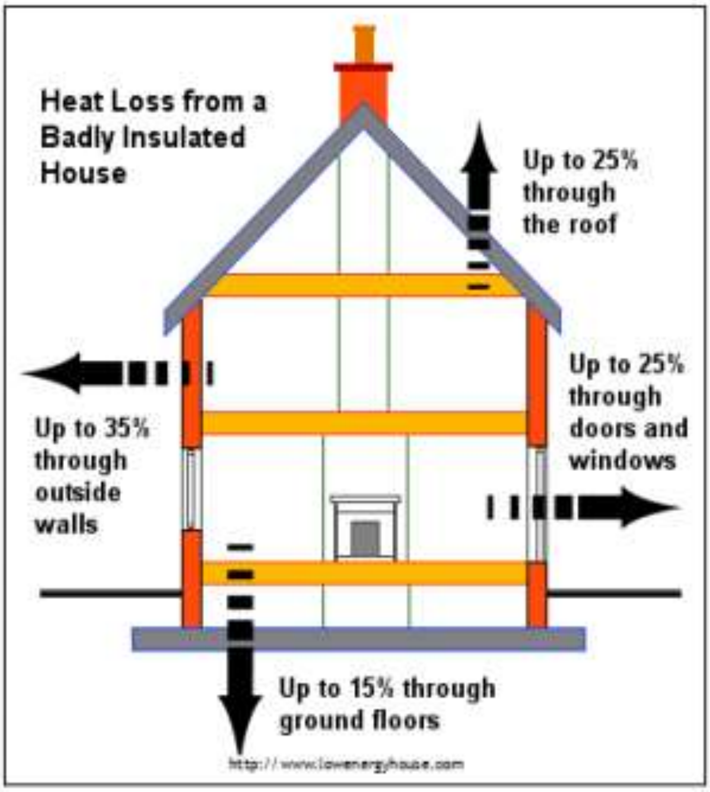
This leads to a short-lived, **localized** increase in pressure, and so this part of the fluid expands. (It's very similar to the section where V/T = constant, i.e. gases expanding at constant pressure).

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.

Example past exam question:

2. A semi-detached house is poorly insulated.
The owner has £3 200 available to spend on improving the insulation.
Information on each type of insulation is shown in the table below.

Part of house	Insulated or not	Heat energy lost per second (W)	Cost of insulation (£)	Payback time (years)	Expected annual saving (£)
LOFT	No insulation	4 200			
	Fibre glass laid on floor of loft	1 500	800	....	200
CAVITY WALL	No insulation	3 000			
	Insulated with foam	1 300	1 200	10	120
DOORS	Wood	1 200			
	PVCu	1 000	1 200	60	....
WINDOWS	Single glazed	1 500			
	Double glazed	1 200	2400	96	25

(a) Complete the spaces in the last **two** columns of the table. [2]

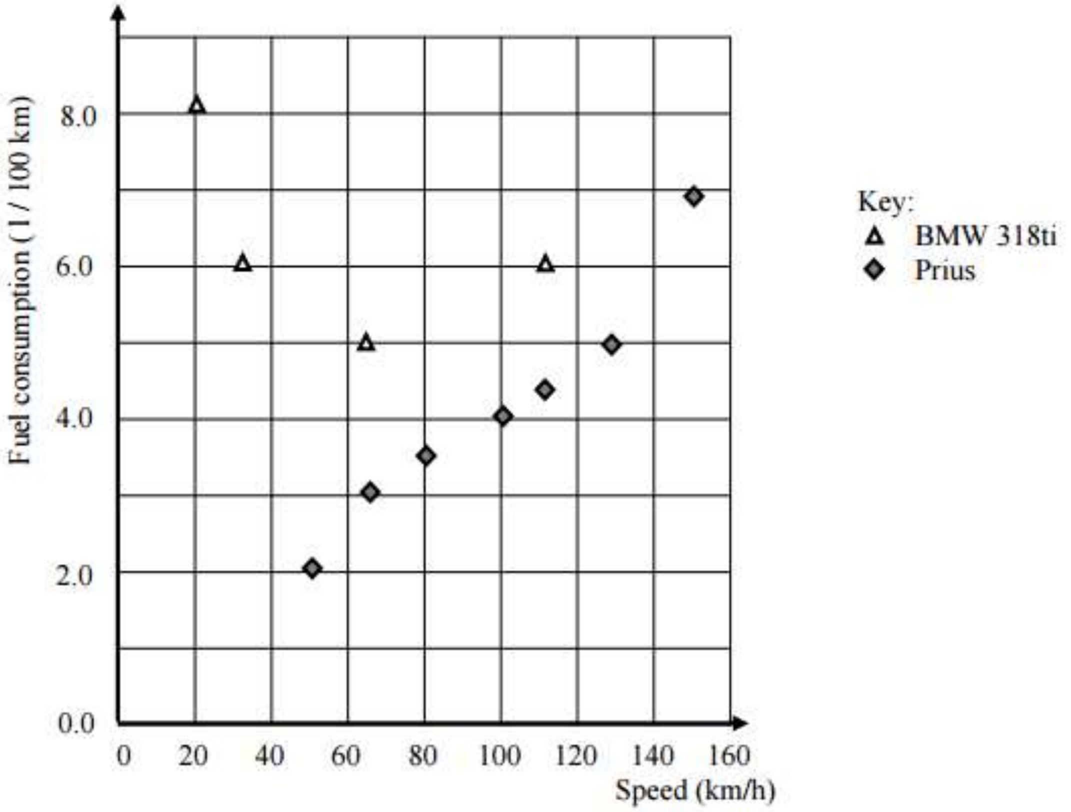
(b) Use information from the table opposite to advise the owner on how best to spend all the £3 200 on insulation. [6 QWC]

ANSWER:

The advantages of insulating the loft are of primary importance. The money spent is the least, it is recouped in the shortest time and gives the greatest gain in energy loss reduction (2 700 W), this accounts for £800 of the spending money. The cavity wall insulation is of second priority with an outlay of £1200, a payback time of just 10 years and the next greatest energy saving of 1 700 W. The remaining money of £1200 is better spent on replacing their doors because of the smaller payback time. The doors have a payback time of 60 years but save only 200 W in total. [The total spend is £3 200 with an annual saving of £340 giving a payback time of 9.4 years.]

In Europe, car drivers compare the amount of fuel they use in "litres per hundred kilometres" rather than miles per gallon.

The driver of a BMW 318ti and the driver of an energy saving Prius measured their fuel consumption when driving at steady speeds. These are their results:



(a) Suggest how other car drivers could make similar measurements for their own car. [2]

....

....

....

....

State carefully what you can conclude about the most economical driving speed for the BMW318ti. [2]

....

....

....

What would the BMW318ti driver need to do to give an improved answer to *(c)*? [1]

....

....

ANSWERS;

(a)	Realistic method of maintaining [roughly] steady speed over a measured distance, e.g. on motorway in low use period, using the car's distance meter (1) Realistic method of measuring fuel use, e.g. fill up – drive [a long distance] – fill up (1) [For 1 mark, allow any suggestion of measuring the distance and fuel consumption at [approximately] a steady speed]	2
(c)	The most economical driving speed is around 60 km/h [accept 55 – 70 or figure in this range](1) but there are too few data points to be sure [and graph goes down and up] [or equiv.](1);	2
(d)	Measure consumption at more different speeds around 60 km /h [or , e.g. measure consumption at 55, 65, 75 [and 85] km/h] or equiv.	1

Investigation of the methods of heat transfer

Introduction

Heat can be transferred through materials (and indeed empty space) in different ways. This series of experiments explores the methods of heat transfer and aims to develop your understanding of the differences between conduction, convection and radiation.

Apparatus

Convection:
2 × 250 cm^3 beaker
1 crystal of potassium manganate(VII)
10 cm^3 glass tube
tripod and gauze
heat proof mat
Bunsen burner
forceps

Radiation:
filament lamp
2 × thermometers
1 small piece of black paper
1 small piece of silver foil
Sellotape
stopwatch
2 × clamp stand, clamp and boss

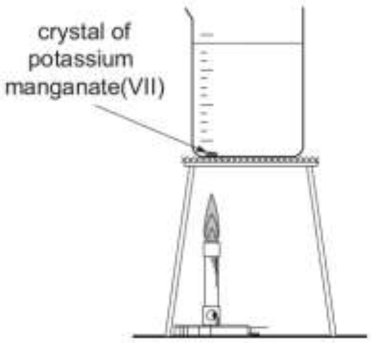
Conduction:

EITHER
4 × metal rods
(aluminium, brass, copper and iron)
4 × drawing pins
Vaseline
tripod
Bunsen burner
heat proof mat
stopwatch

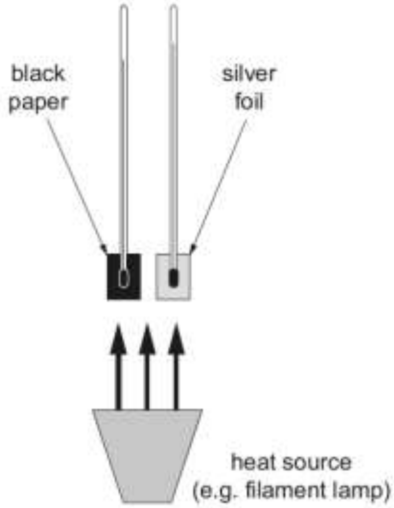
OR
conductive ring
(aluminium, brass, copper and steel)
4 × wooden matches
Vaseline
clamp stand, clamp and boss
Bunsen burner
heat proof mat
stopwatch

Diagram of Apparatus

Convection Experiment

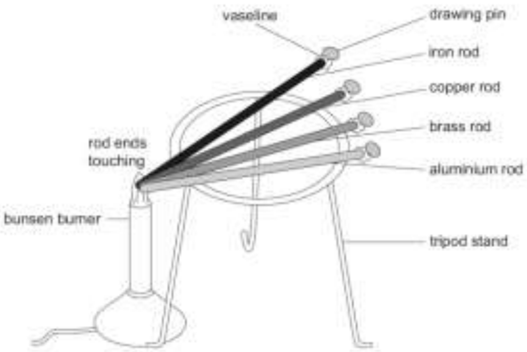


Radiation Experiment

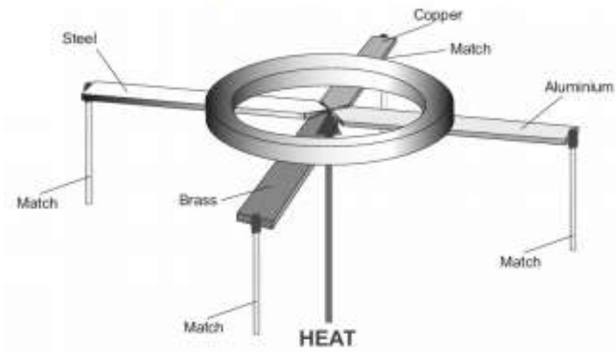


Conduction Experiment

EITHER
Metal Rods Experiment



OR
Conductive Ring Experiment



Method

Convection Experiment

1. Fill the beaker to ¾ full of water.
2. Use forceps to pick up a single crystal of potassium manganate(VII) and drop it carefully
   through the glass tube to one side of the bottom of the beaker.
3. Place your finger on the top of the tube and remove carefully.
4. Light the Bunsen burner well away from the apparatus. Use the gas tap to get the smallest
   blue flame that you can.
5. Put the small Bunsen flame directly underneath the crystal and record your observations.

Method

Radiation Experiment

1. Use Sellotape to attach a 2 cm strip of black paper to the bulb of one thermometer.
2. In the same way attach a 2 cm strip of silver foil to the bulb of another thermometer.
3. Clamp the 2 thermometers **the same distance away** (about 10 cm) from a filament lamp.
4. Record the temperatures shown by the two thermometers.
5. Switch on the lamp and record the temperatures again after 10 minutes.

Analysis

1. Determine which colour is the best absorber of heat.

Method

Conduction Experiment

<u>Metal Rods Experiment</u>

1. Set up the apparatus as shown in the diagram above.
2. Attach a drawing pin to the end of each rod with a small blob of Vaseline.
3. The ends of the rods (without the drawing pins) should be brought together so that they can be heated equally (see diagram).
4. Heat the ends of the rods equally with a blue Bunsen flame.
5. Record the time taken for each rod to lose its drawing pin.

Conductive Ring Experiment

1. Clamp the conductive ring taking care to keep the clamp away from the mid-point of the ring.
2. Attach a wooden match to the outer end of each metal using a small blob of Vaseline.
3. Heat the centre point of the ring with a blue Bunsen flame.
4. Record how long it takes for each metal to lose its wooden match.

Analysis

1. Determine the order of conductivity of the metals.

Risk Assessments

Convection Experiment

Hazard	Risk	Control measure
Potassium manganate(VII) is harmful/oxidising	Could harm skin if touched	Use tweezers to drop a single crystal through the glass tube to bottom of beaker. Do not handle
Hot apparatus can burn	Burning fingers when moving apparatus	Allow apparatus to cool before any attempt to move it. Hold tripod at bottom of a leg, Bunsen burner at base and gauze at the corner.

Radiation Experiment

Hazard	Risk	Control measure
Hot filament lamp can burn	Burning fingers when moving lamp	Allow lamp to cool before any attempt to move it.

Conduction Experiment

Hazard	Risk	Control measure
Hot metal rods can burn	Burning fingers when moving rods	Allow the rods to cool thoroughly before attempting to move them from the tripod
Hot tripod can burn	Burning fingers when moving tripod	Allow the tripod to cool. Do not touch the top. Move by holding bottom of a leg
Aluminium melting can burn	Molten aluminium falling on back of hand causing burning/injury	Do not overheat aluminium. Observe aluminium for signs of melting and remove heat. Do not hold the Bunsen when it is directly beneath end of aluminium rod

Determination of the density of liquids and solids (regular and irregular)

Introduction

The density of a substance measures the mass it contains in a given volume. Density is calculated using the equation:

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$

Apparatus

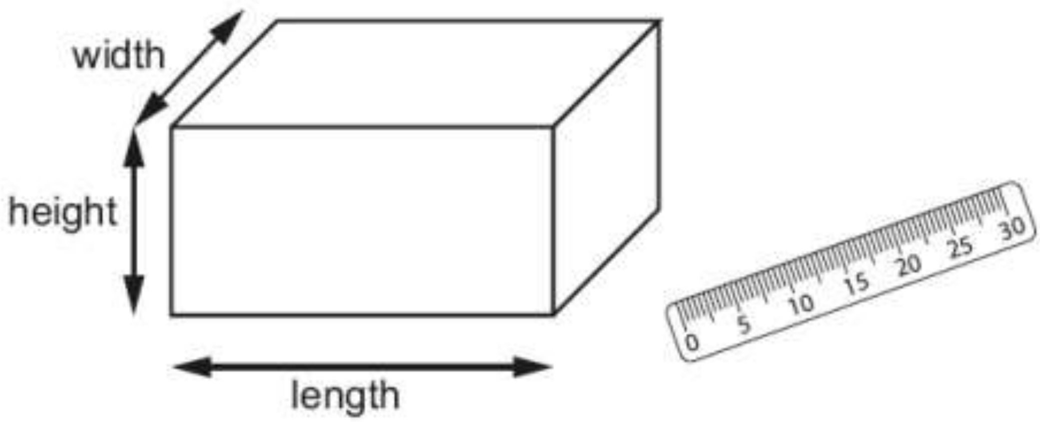
2 × regular shaped solids
2 × irregular shaped solids
30 cm ruler
50 cm^3 measuring cylinder
water

Access to:

electronic balance ± 0.1 g

Measuring the density of a regular shaped solid

Diagram of Apparatus



Method

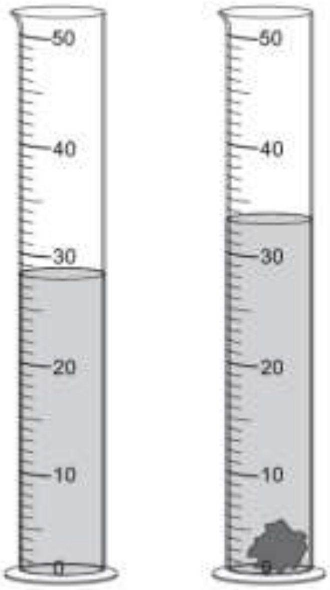
1. Record the mass of the solid.
2. Record the length, width and thickness of the solid using a ruler.
3. Repeat for cubes of different material.

Analysis

1. Calculate the volume of the cube from: volume = length x height x width.
2. Calculate the density in g/cm^3.

Measuring the density of an irregular shaped solid

Diagram of Apparatus



Method

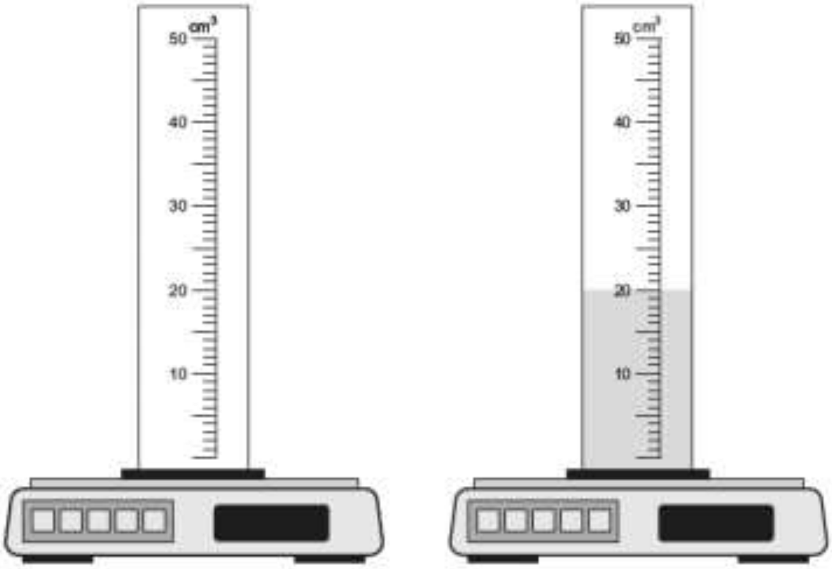
1. Record the mass of the solid.
2. Fill the measuring cylinder with water up to 20 cm^3 and record the volume.
3. Gently place the solid into the measuring cylinder and record the new volume.

Analysis

1. Calculate the volume of the solid by subtracting the original volume from the new volume.
2. Calculate the density in g/cm^3.

Measuring the density of a liquid

Diagram of Apparatus



Method

1. Record the mass of the empty measuring cylinder.
2. Add 20 cm^3 of water to the measuring cylinder.
3. Record the mass of the measuring cylinder with the water.

Analysis

1. Calculate the mass of the water by subtracting the mass of the measuring cylinder (without water) from the mass of the measuring cylinder with the water.
2. Calculate the density in g/cm^3.

Unit 1.4 – Domestic Energy

(a) the kilowatt (kW) as a convenient unit of power in the domestic context and the kilowatt hour (kWh) as a unit of energy

(b) the cost of electricity using the equations:

units used (kWh) = power (kW) × time (h)
cost = units used × cost per unit

(c) how data can be obtained either directly or using secondary sources (e.g. through the energy banding (A-G) and the power ratings of domestic electrical appliances) to investigate the cost of using them

(d) the difference between alternating current (a.c.) and direct current (d.c.)

(e) the functions of fuses, miniature circuit breakers (mcb) and residual current circuit breakers (rccb) including calculations of appropriate fuse ratings

(f) the ring main, including the functions of the live, neutral and earth wires

(g) the cost effectiveness of introducing domestic solar and wind energy equipment, including fuel cost savings and payback time by using data

(h) how to investigate energy transfers in a range of contexts including interpreting and analysing data; evaluation of validity of the data and methods, e.g.

- the energy output from a renewable source (e.g. wind turbine: construction and location)
- efficiency of energy transfer (e.g. using an electric kettle)

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.

÷ 1000: W → kW

÷ 60: minutes → hours

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

Cost = 0.425 × 12 pence = 5.1 pence

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 ÷ 1800 = 3 (1 mark)

3 x 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).

It is possible to determine the efficiency of an electrical appliance in fairly simple experiments. Here is one example:

Method 3: Electric Kettle

The last method of heating water that we are testing is an electric kettle.

1.) Measure 1 litre of water into the kettle.
2.) Take the initial temperature of the water.
3.) Start the stop clock and switch the kettle on.
4.) Stop the stop clock when the kettle boils.

Initial temperature of water: ________________ °C

Time taken to boil 1 litre of water: _________________seconds

The kettle boils water at 100°C, so the total temperature rise = 100 – initial temperature.

Total temperature rise = ______________ °C

The kettle has a power of 2.5 kW. This means that it uses 2500 J of energy every second. This means that we can work out how much energy we have put into our water.

$$Total\ energy\ input = 2500\ x\ time\ in\ seconds$$

5.) Calculate the total energy from the kettle:

We can work out how much useful energy went into the water using the temperature rise.

$$Useful\ energy\ out = 4200\ x\ temperature\ rise$$

6.) Calculate the useful energy that was transferred to the water:

Now we can find the efficiency of our kettle.

$$Efficiency\ (\%) = \frac{useful\ energy\ out}{total\ energy\ in}\ x\ 100$$

7.) Use the numbers that you have written down for steps (5.) and (6.) to calculate the efficiency of heating water with a kettle.

Reducing energy consumption

Around the world, the demand for energy has never been greater than it is today. Most of the energy that we rely on to power our cars, heat and cool our homes and run electronic devices is produced from non-renewable sources such as coal, natural gas and oil. These non-renewable energy sources are limited in supply and burning them adds greenhouse gases to the atmosphere. More and more people are realising that these greenhouse gases increase the risk of globing warming and that may cause climate change.

In Australia, climate change is likely to:

- cause more frequent and intense droughts, storms and floods
- assist the spread of diseases, especially mosquito-borne diseases such as dengue fever and Ross River virus
- alter the populations of different species of plants and animals, especially those that live above the snowline in the southern states.

Reducing the amount of energy we use reduces the amount of greenhouse gases put into the atmosphere. We can reduce energy consumption in many ways, such as by switching off lights, computers and televisions when they are not in use. Walking, cycling or using public transport instead of relying on the family car will reduce your household's energy consumption. Replacing highly inefficient incandescent globes with more efficient compact fluorescent globes has already cut the energy bills of most households. Table 5.3.1 compares the efficiencies of incandescent and fluoroescent globes.

Table 5.3.1 Comparison of incandescent and compact fluorescent globes

Power	Approximate balloons of greenhouse gas produced over its lifespan	Purchase price	Expected operating hours	Approximate cost per year
75 watt incandescent 	 3600	$1.00–1.20	1000–2000	$12.30
15 watt (75 watt equivalent) fluorescent 	 730	$4.00–10.00 (cheaper if buying a pack of 2 or 3)	Around 8000 hours	$2.30

See the light!

SciFile

Old-fashioned incandescent light globes converted most of their electricity into heat. The compact fluorescent globes available today use about 80% less electricity to produce the equivalent amount of light.

Comparing labels

SciFile

The energy rating label was first used in New South Wales and Victoria in 1986. Today, any household refrigerator, freezer, television, washing machine, clothes dryer, single-phase air conditioner or dishwasher sold in Australia must carry an approved energy rating label. It's the law!

Energy rating labels

Household appliances vary in their energy efficiency. By purchasing appliances that are more efficient, your household will save energy and save on running costs. If you look around shops selling electrical appliances you will see that most large appliances carry a red and yellow **energy rating label**. A sample label is shown in Figure 5.3.1.

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Energy efficiency is shown by the number of stars on the label. The more stars (usually from 1 to 6) that are shaded on the energy rating label, the greater the energy efficiency of the appliance. You can determine which models are the most energy efficient by comparing the number of stars. The number found on the label provides the customer with an estimate of the amount of energy (usually listed in kilowatt hours per year) needed to operate the appliance for one year. The higher the number, the more energy is needed and the more the appliance will cost to run.

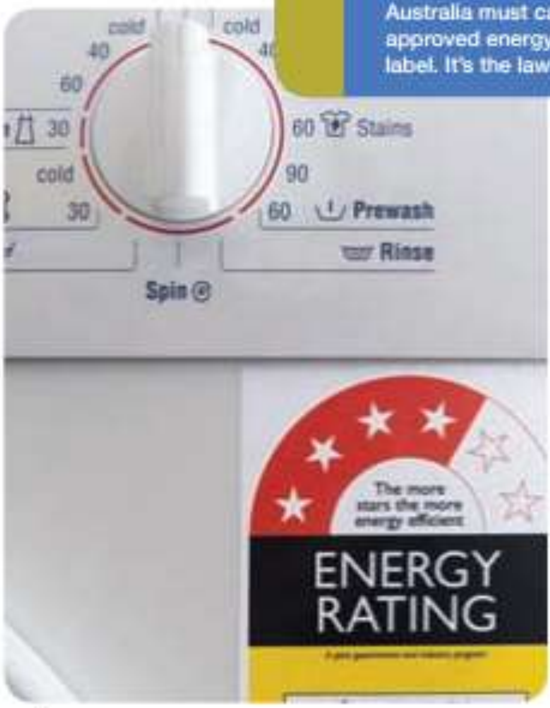


Figure 5.3.1 Appliances are tested under Australian standards to produce an energy rating label. Greater energy efficiency is indicated by more stars (or half stars) out of a possible six stars.

SciFile

How much energy is that?

Energy rating labels display the typical amount of energy an appliance will use over one year. This value is stated in kilowatt hours. One kilowatt hour is equal to 3 600 000 joules of energy. This can also be written as 3.6 megajoules (MJ).

Efficient housing

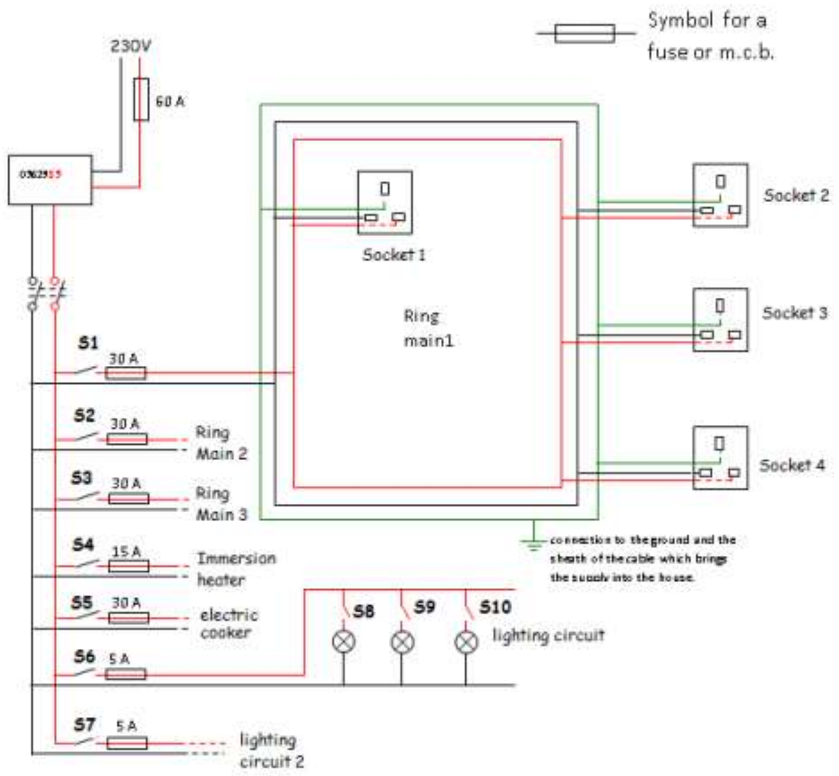
Living in an energy-efficient house makes it easier for households to reduce their energy consumption. It is estimated that about half of the energy costs of running a house are to keep it warm in winter and cool in summer. Heat naturally flows from regions of higher temperature to regions of lower temperature. In winter, the warm air from a heater or heating system can flow through any cracks or gaps in the walls to the cool air outside or into the cooler garage. Alternatively, heat can rise up into the roof space. This means that a lot of energy is needed to keep a leaky house warm in winter. Similarly, in summer, the warm air outside will naturally flow into a cool house. To keep the house cool, air-conditioners might be used. However, they use a lot of energy, making them expensive to run. Adding **insulation** to ceilings and between the walls of a home reduces the heat flowing outside in winter and inside in summer. This makes heating and cooling more effective and makes a house more comfortable.

5.7

Figure 5.3.2 This zero emissions house has been constructed in a Victorian housing estate. Over the course of a year, solar panels on the roof generate as much energy as the house will use.

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?

$P = V \times I$

$= 230 \times 30$

$=$ <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.

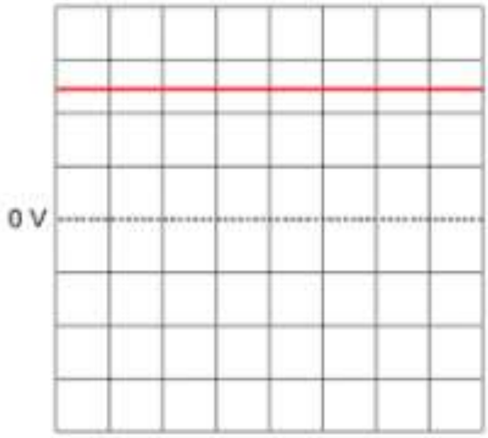
Total current for all bulbs = 0.05 + 0.05 + 0.05 = 0.15 A

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

Direct current and alternating current

You should know the differences between direct current (d.c.) and alternating current (a.c.) electrical supplies.

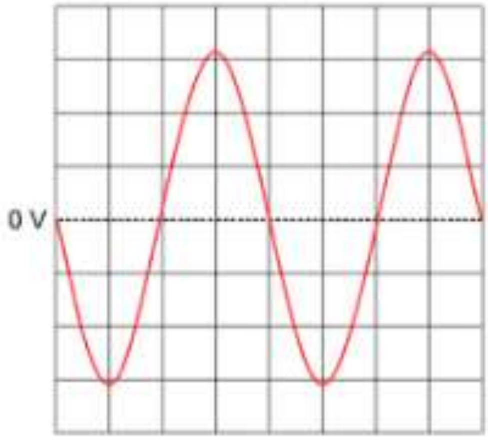
Direct current



Direct current

If the *current* flows in only one direction it is called direct current, or d.c. Batteries and cells supply d.c. electricity, with a typical battery supplying maybe 1.5V. The diagram shows an oscilloscope screen displaying the signal from a d.c. supply.

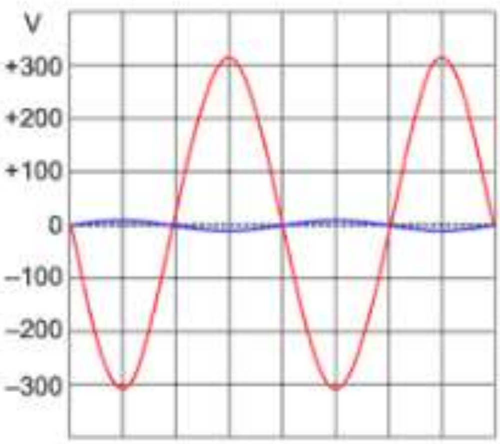
Alternating current



Alternating current

If the current constantly changes direction, it is called alternating current, or a.c.. Mains electricity is an a.c. supply, with the UK mains supply being about 230V. It has a *frequency* of 50Hz (50 hertz), which means it changes direction, and back again, 50 times a second. The diagram shows an oscilloscope screen displaying the signal from an a.c. supply.

Alternating current - higher



Alternating current

The potential difference of the live terminal varies between a large positive value and a large negative value. However, the neutral terminal is at a potential difference close to earth, which is zero. The diagram shows an oscilloscope screen displaying the signals from the mains supply. The red trace is the live terminal and the blue trace the neutral terminal. Note that, although the mean voltage of the mains supply is about 230V, the peak voltage is higher.

The UK mains electricity supply is about 230V and can kill if not used safely. Electrical circuits, cables, plugs and appliances are designed to reduce the chances of receiving an electric shock. The more electrical energy used, the greater the cost. Electrical supplies can be direct current (d.c.) or alternating current (a.c.).

Wiring a plug

You should know the features of a correctly wired three-pin mains electricity plug and be able to recognise errors in the wiring of a plug.

The cable

A mains electricity cable contains two or three inner wires. Each has a core of copper, because copper is a good conductor of electricity. The outer layers are flexible plastic, because plastic is a good electrical *insulator*. The inner wires are colour coded:

Colours of inner wires within a cable

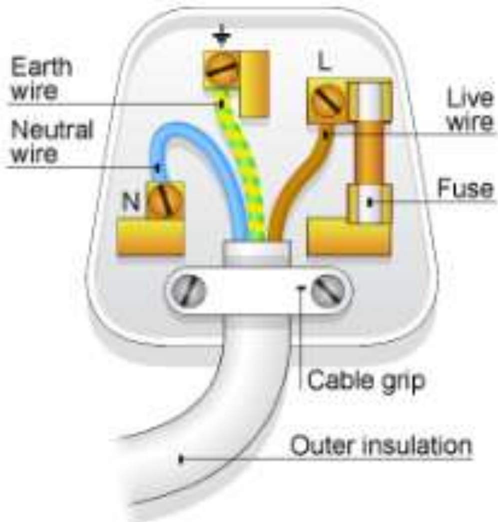
colour	wire
blue	**neutral**
brown	**live**
green and yellow stripes	**earth**

The plug

The features of a plug are:

- The case is made from tough plastic or rubber, because these materials are good electrical insulators.
- The three pins are made from brass, which is a good conductor of electricity.
- There is a *fuse* between the live terminal and the live pin.
- The fuse breaks the circuit if too much current flows.
- The cable is secured in the plug by a cable grip. This should grip the cable itself, and not the individual wires inside it.

The diagram shows the key features of a correctly wired three-pin mains plug.



The inside of a plug

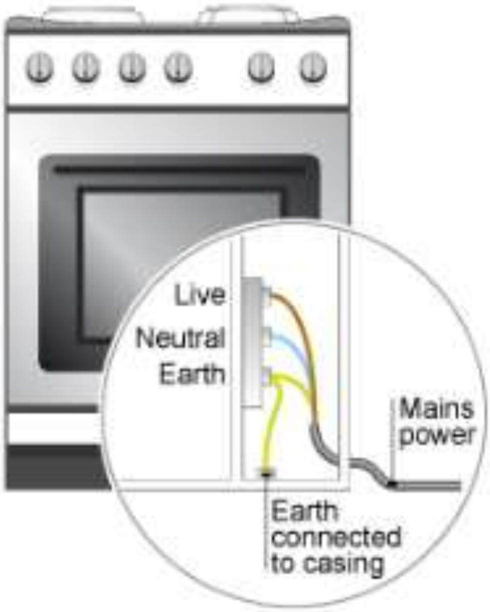
Earthing

You should understand why electrical appliances are earthed.

Earthing

Many electrical appliances have metal cases, including cookers, washing machines and refrigerators. The earth wire creates a safe route for the current to flow through if the live wire touches the casing.

You will get an electric shock if the live wire inside an appliance, such as a cooker, comes loose and touches the metal casing. However, the earth terminal is connected to the metal casing so that the current goes through the earth wire instead of causing an electric shock. A strong current surges through the earth wire because it has a very low resistance. This breaks the fuse and disconnects the appliance.



Earthing of an electric cooker

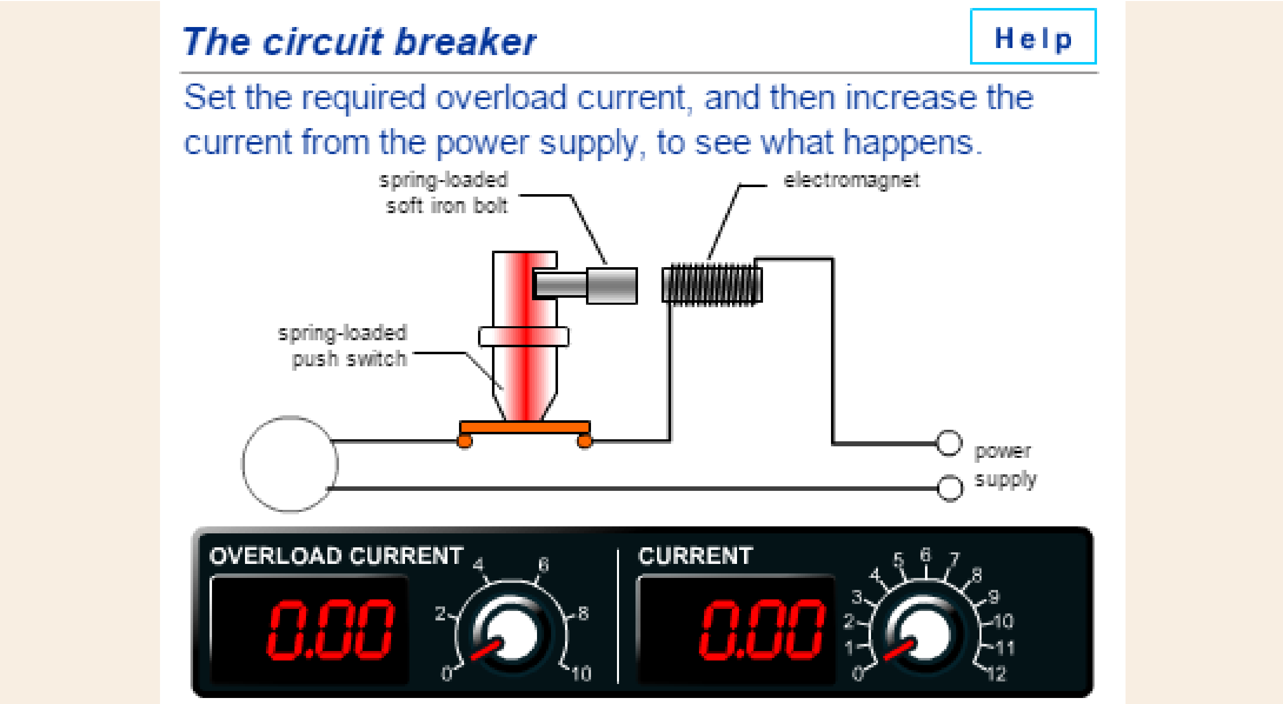
Fuses and circuit breakers

Fuses and circuit breakers protect electrical circuits and appliances.

The circuit breaker

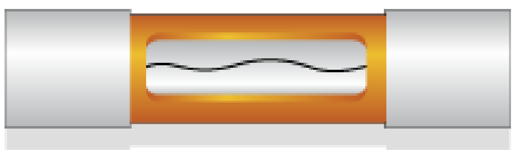
The circuit breaker does the same job as the fuse, but works in a different way. A spring-loaded push switch is held in the closed position by a spring-loaded soft iron bolt. An electromagnet is arranged so that it can pull the bolt away from the switch. If the current increases beyond a set limit, the electromagnet pulls the bolt towards itself, which releases the push switch into the open position.

Use this simulation to see how circuit breakers work.



The fuse

The fuse breaks the circuit if a fault in an appliance causes too much current flow. This protects the wiring and the appliance if something goes wrong. The fuse contains a piece of wire that melts easily. If the current going through the fuse is too great, the wire heats up until it melts and breaks the circuit.



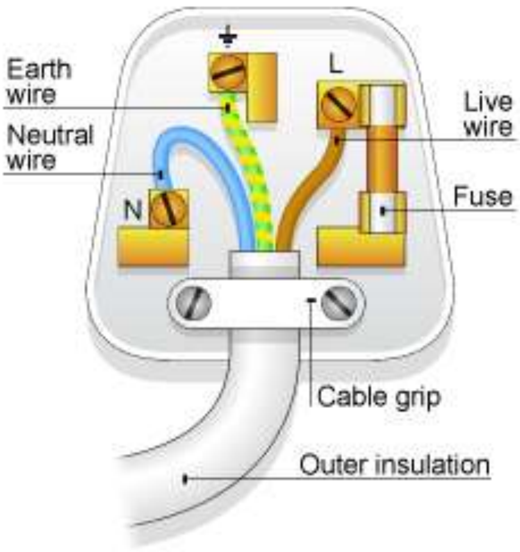
A 13A fuse with a low melting point wire

Fuses in plugs are made in standard ratings. The most common are 3A, 5A and 13A. The fuse should be rated at a slightly higher current than the device needs:

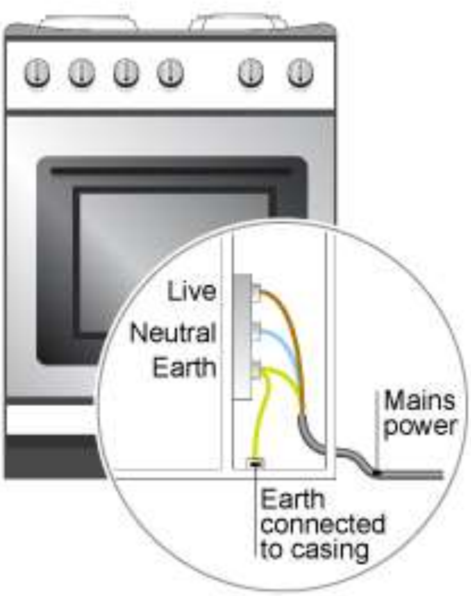
- if the device works at 3A, use a 5A fuse
- if the device works at 10A, use a 13A fuse

Cars also have fuses. An electrical fault in a car could start a fire, so all the circuits have to be protected by fuses.

Live, neutral and earth wires



The inside of a plug



A lot of **mains powered** appliances need three wires to work safely. Only two of the wires are used when the appliance works properly. These are the **live** (brown) and the **neutral** (blue) wires. The live wire carries **current** to the appliance at a high voltage. The neutral wire completes the **circuit** and carries current away from the appliance. The third wire, called the **earth** wire (green/yellow) is a safety wire and connects the metal case of the appliance to the earth. This stops a **fault** making the case of the appliance **live**.

If a fault occurs where the live wire connects to the case, the earth wire allows a **large current** to flow through the live and earth wires. This overheats the fuse which melts and **breaks** the circuit.

Appliances such as hairdryers are said to be 'double insulated' and there's no need for an earth wire because the case is made of a non conducting plastic. If a faulty live wire touches the inside of the plastic case there's little risk as the case is an **insulator**.

Unit 1.5 – Features of Waves

(a) the difference between transverse and longitudinal waves

(b) the description of a wave in terms of amplitude, wavelength (λ), frequency (f) and wave speed (v)

(c) the graphical representation of a transverse wave, including labelling the wavelength and amplitude

(d) diagrams showing plane wave fronts being reflected or refracted, e.g. as shown by water waves in a ripple tank

(e) refraction in terms of the speed of waves on either side of a refracting boundary and the effect on the wavelength of the waves

(f) the term "radiation" to both electromagnetic waves and to energy given out by radioactive materials

(g) the characteristics of radioactive emissions and short wavelength parts of the electromagnetic spectrum (ultraviolet, X-ray and gamma ray) as ionising radiation, able to interact with atoms and to damage cells by the energy they carry

(h) the difference between the different regions of the electromagnetic spectrum [radio waves, microwaves, infra-red, visible light, ultraviolet, X-rays and gamma rays] in terms of their wavelength and frequency and know that they all travel at the same speed in a vacuum

(i) the fact that all regions of the electromagnetic spectrum transfer energy and certain regions are commonly used to transmit information

(j) waves in terms of their wavelength, frequency, speed and amplitude

(k) the equations:
wave speed = wavelength × frequency; $v = \lambda f$ and

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

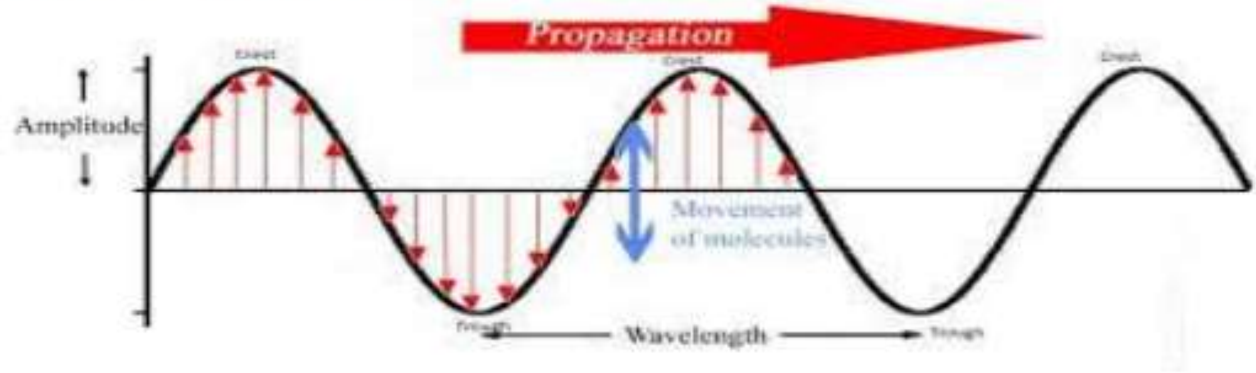
applied to the motion of waves, including electromagnetic waves

(l) communication using satellites in geosynchronous/geostationary orbit

SPECIFIED PRACTICAL WORK

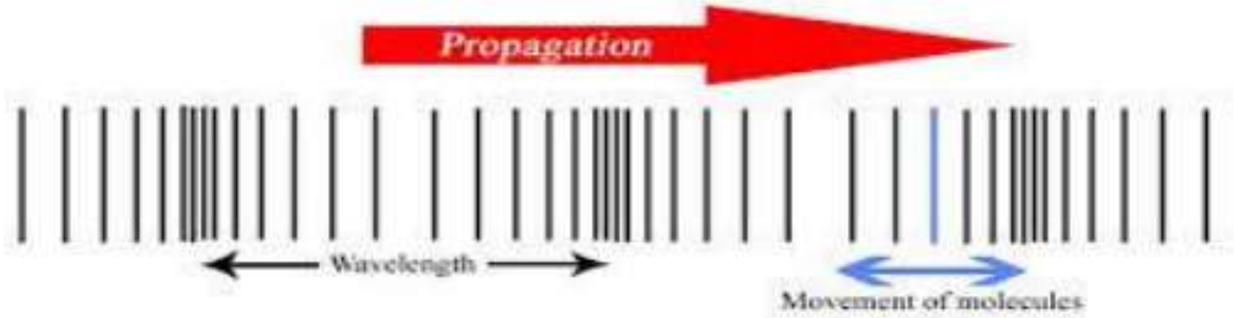
- Investigation of the speed of water waves

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.***

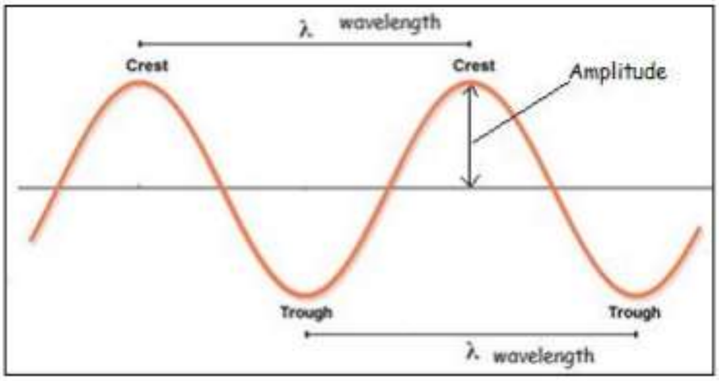


Examples: Sound waves, P-waves

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
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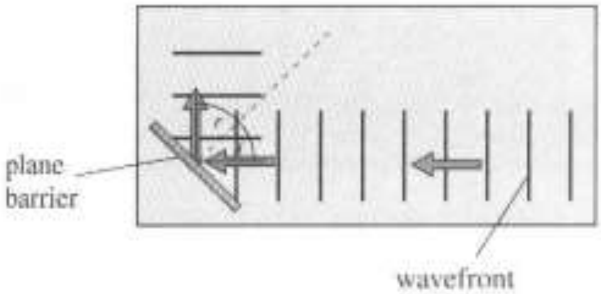
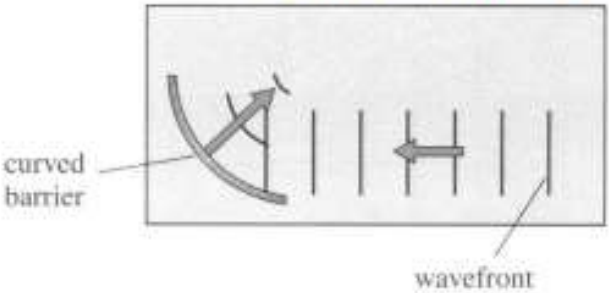
3. Amplitude	Distance from the middle of the wave to the crest/top. The greater the amplitude the more energy the wave is carrying.	Metres, m
4. Speed c	The distance travelled by the wave in 1 second.	Metres per second, m/s.

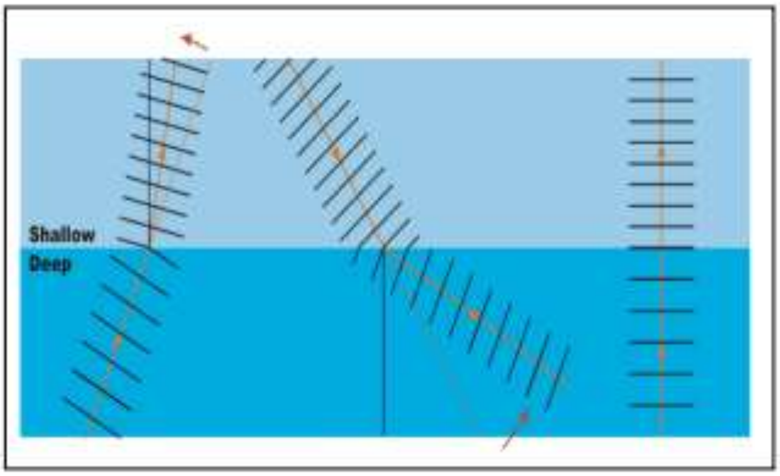
Reflection. As the waves strike a plane (flat) barrier they are reflected. This is very similar for a beam of light reflecting on a plane mirror. If a curved (concave) barrier such as a satellite dish is used, the waves can be made to converge (concentrate) at a point. The angle of incidence and reflection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

Reflection on a satellite dish.



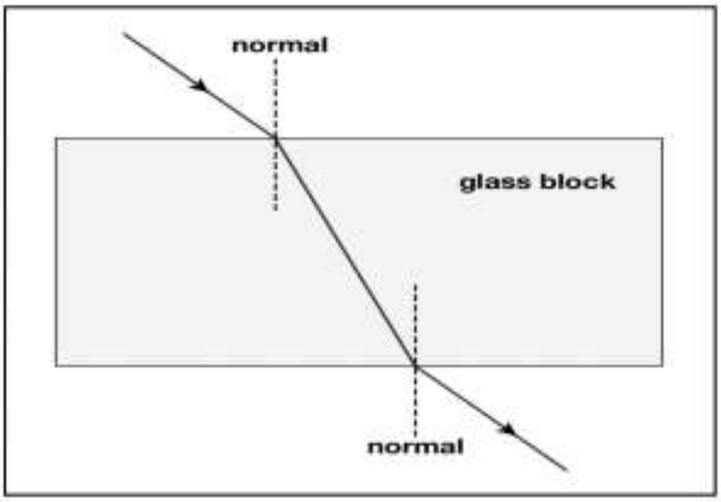


Refraction: Refraction is the change in direction of a wave at the boundary between two materials. This is caused by a change in speed.



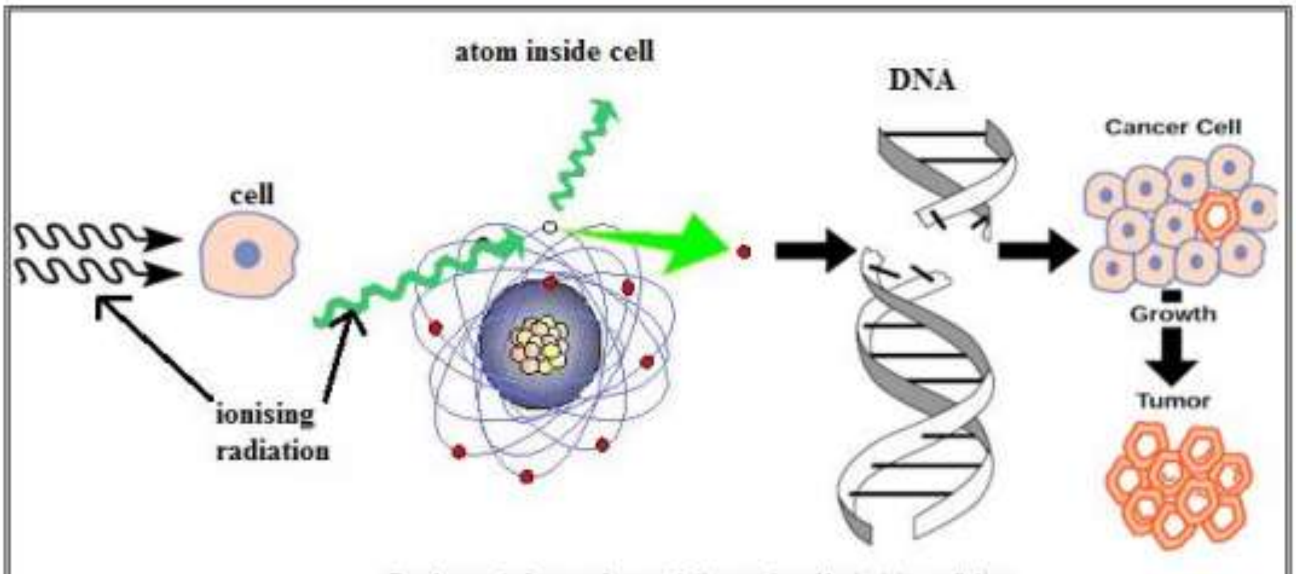
Water. This occurs when water waves pass between deep and shallow water. The waves move more slowly in shallow water. The ***frequency of the waves remain constant*** and so the wavelength decreases. When the waves move from shallow to deeper water, their speed increase and they change direction away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



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.



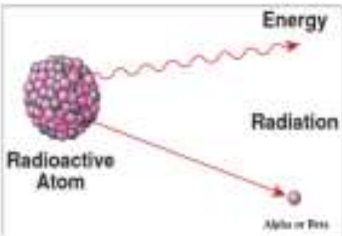
Development of cancer from mutation produced by ionizing radiation.

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

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

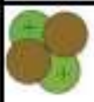
Radioactive decay:

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.



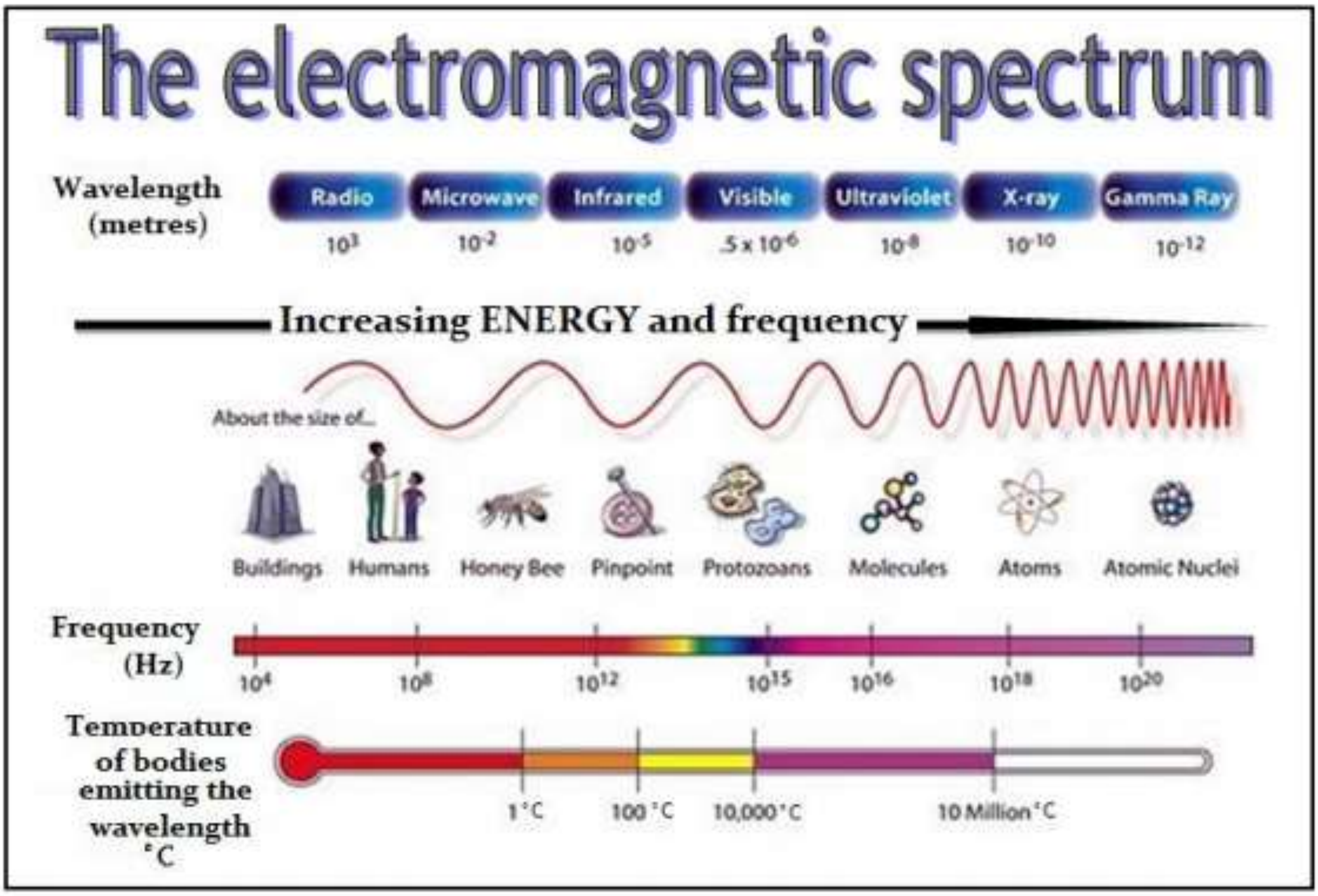
Alpha, beta and gamma radiation.

The 3 types of radioactive emissions from a nucleus.

Properties	**Alpha**	**Beta**	**Gamma**
Symbol	α	β	γ
What is it?	 A helium nucleus (2 protons and 2 neutrons).	 Fast moving electron.	High energy electromagnetic wave.
Charge	+2	-1	0
Speed	10% speed of light.	50% speed of light.	Speed of light.
What can stop it?	Thin sheet of paper or few cm of air.	Few mm of aluminium or a few metres of air.	Several cm of lead or very thick concrete.
Ionising power.	Very high - most damaging inside the body.	Medium	Low (compared with alpha and beta). Easily passes through the body.

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.**

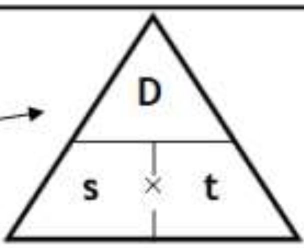
Uses of the em spectrum.

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.

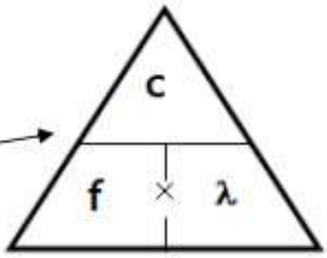
Calculations involving waves.

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 λ



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).

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

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 2^{nd} equation since speed and wavelength are given.

Speed = frequency x wavelength

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

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

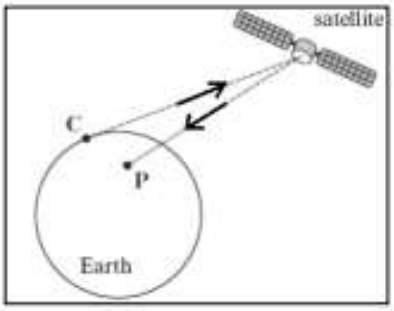
150,000,000 km x 1000 = 150,000,000,000 m or 1.5×10^{11} m

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

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

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

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.

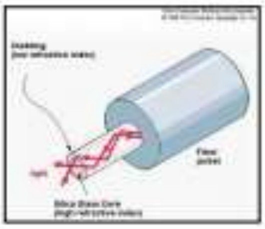
Method 1, satellite: If the distance from the Earth's surface to each satellite is 3.6×10^7 m, what is the total distance the microwaves must travel to go from Wales to Italy?

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.

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

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?



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

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

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

Investigation of the speed of water waves

Introduction

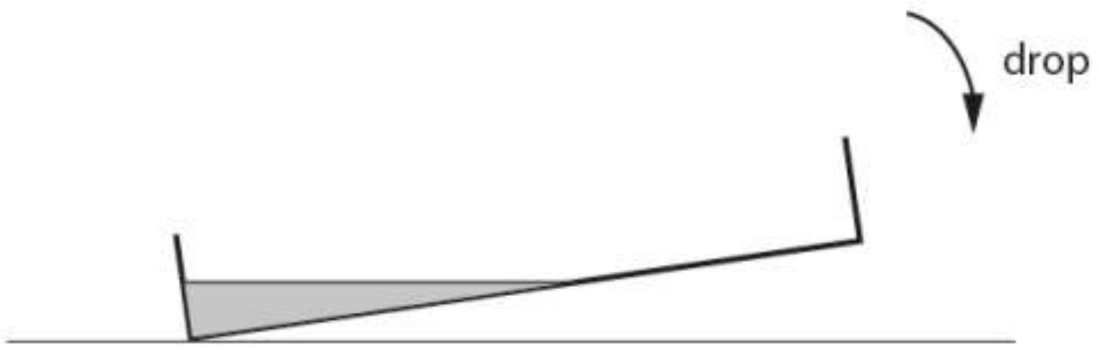
The speed of waves on the surface of water, created when the water is moved out of position, depends only on the depth of the water and the gravitational field strength. To measure the speed of the waves the time they take to travel a certain distance is measured and the following equation is applied.

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

Apparatus

rectangular apparatus tray with straight sides
stopwatch
large beaker
large measuring cylinder

Diagram of Apparatus



Method

1. Measure the length of the tray and record the result.
2. Add water to the tray to give a depth of 0.5 cm and record the volume used.
3. Lift the end of the tray up a few cm and gently replace on the desk.
4. Start the stopwatch when the wave produced hits the end of the tray.
5. Record how long it takes the waves to travel 3 lengths of the tray.
6. Repeat steps 3-5 four more times.
7. Repeat steps 2-6 increasing the depth each time by 0.5 cm up to 3.0 cm.

Analysis

1. Calculate the mean speed of the waves using:

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

2. Plot a graph of depth against speed.

Risk Assessment

Hazard	Risk	Control measure
Wet floors are slippery	If water splashes on the floor during the experiment people may slip and be injured	Do not overfill the trays. Place tray down gently when producing waves. Mop up any spillages