

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
- 1.6 The total internal reflection of waves
- 1.7 Seismic waves
- 1.8 Kinetic theory
- 1.9 Electromagnetism

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;**
$$R = R_1 + R_2; \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$
- (h) power as energy transferred per unit time: $E = Pt$
- (i) the power transferred using:
power = voltage $\times$ current $P = VI$
power = current² $\times$ resistance $P = I^2 R$
- (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

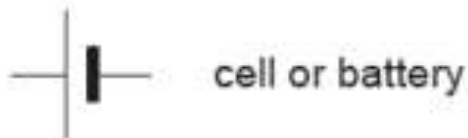
Be able to draw circuit diagrams.



switch



lamp



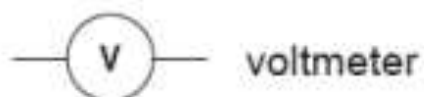
cell or battery



fuse



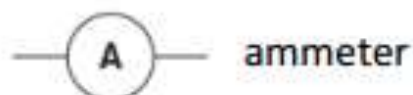
diode



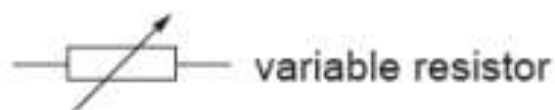
voltmeter



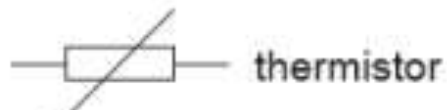
resistor



ammeter



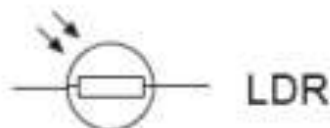
variable resistor



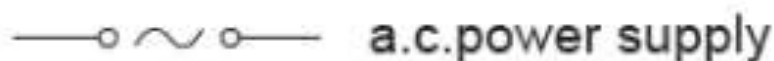
thermistor



LED



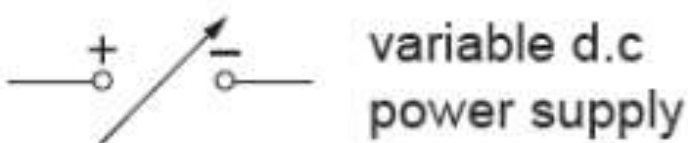
LDR



a.c. power supply



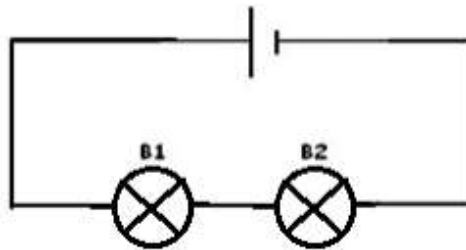
d.c. power supply



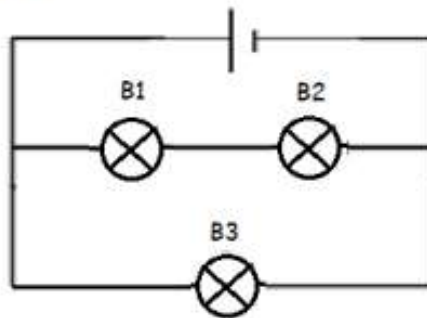
variable d.c.
power supply

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.

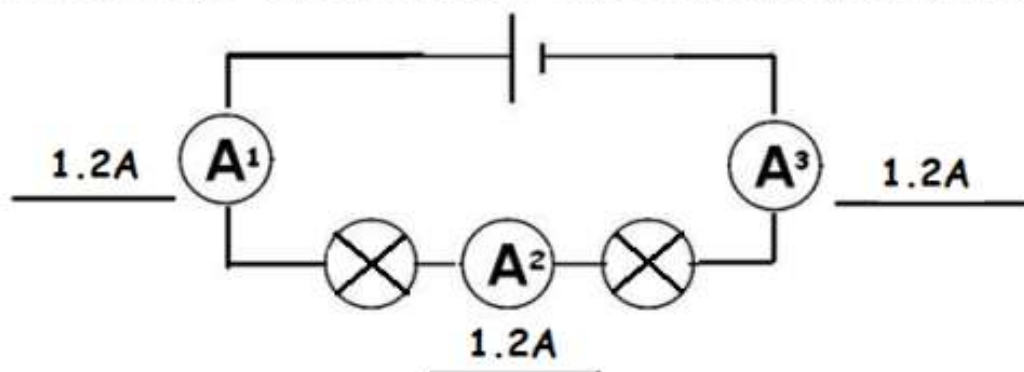


Parallel circuit: in a parallel circuit there is more than one path and the circuit is divided into branches. Bulbs B1 and B2 are in series but B3 is in parallel with them. If bulb B3 breaks then B1 and B2 will continue to work.



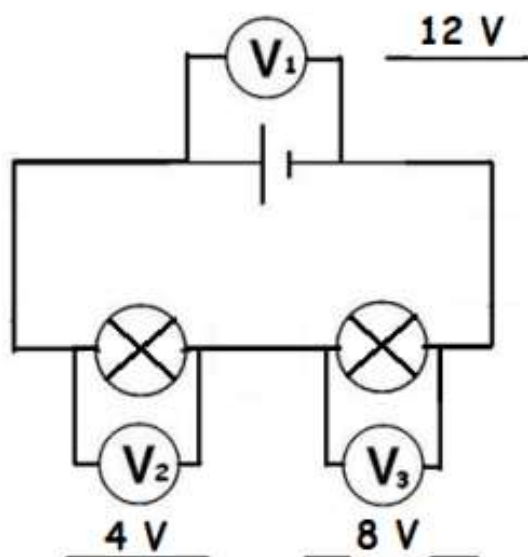
Measuring current and voltage in circuits.

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



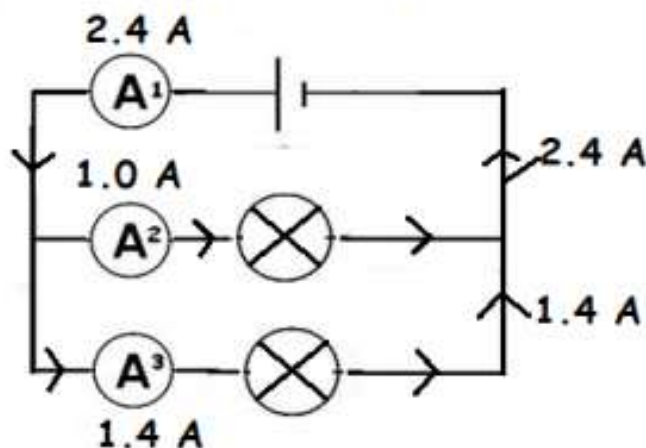
The value of the current is the same at all points ($A_1 = A_2 = A_3$) in the circuit since there is only one path for the current to flow.

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 ($12 = 4 + 8$).

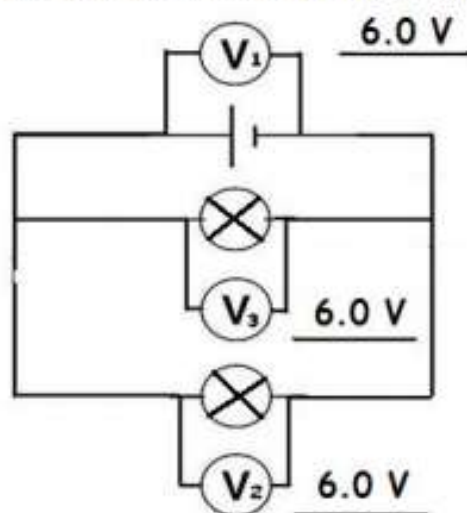
Current in parallel circuits: the ammeter in this series circuit is connected in series.



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 ($2.4 = 1.0 + 1.4$).

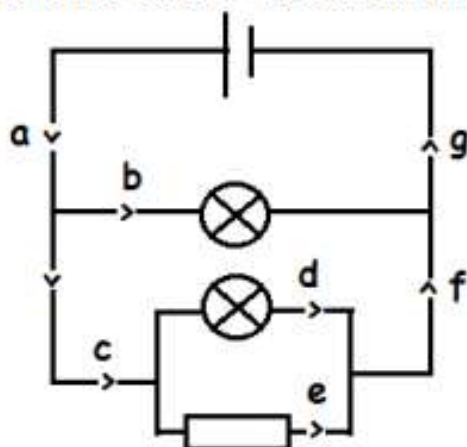
Voltage in parallel circuit: the voltage across all components in parallel is the same.

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.



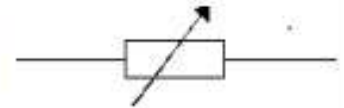
Point	Current (A)
a	3.6
b	2.0
c	
d	1.2
e	
f	
g	

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

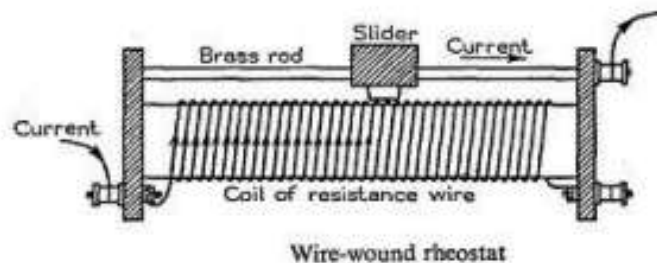
Variable resistors (controlling the current).

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.

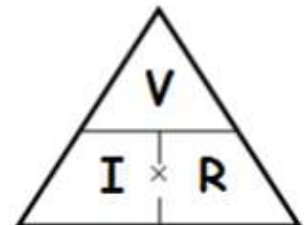


Ohm's law

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

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

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



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

$$V = 1.8 \times 15 = 27 \text{ V}$$

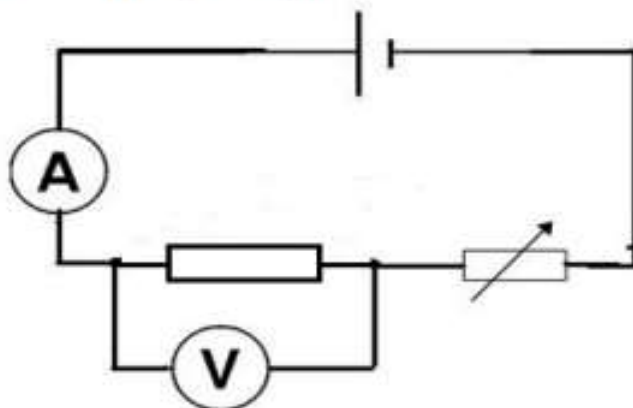
Q1. Calculate the current through a $2k\Omega$ resistor when there is a voltage of 230V across it.

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

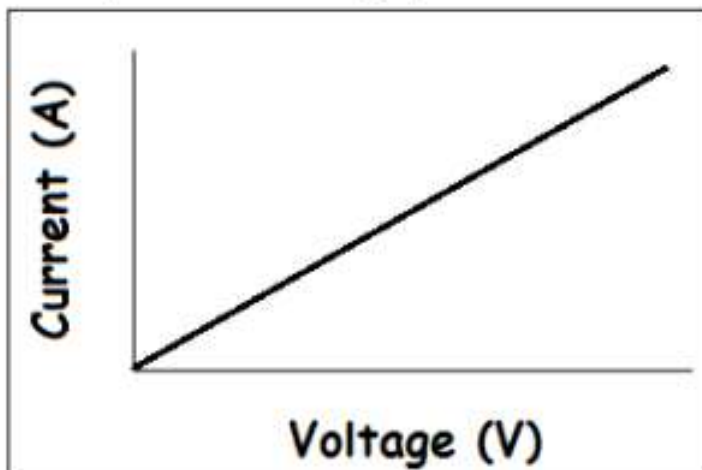
Current - voltage relationship

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

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

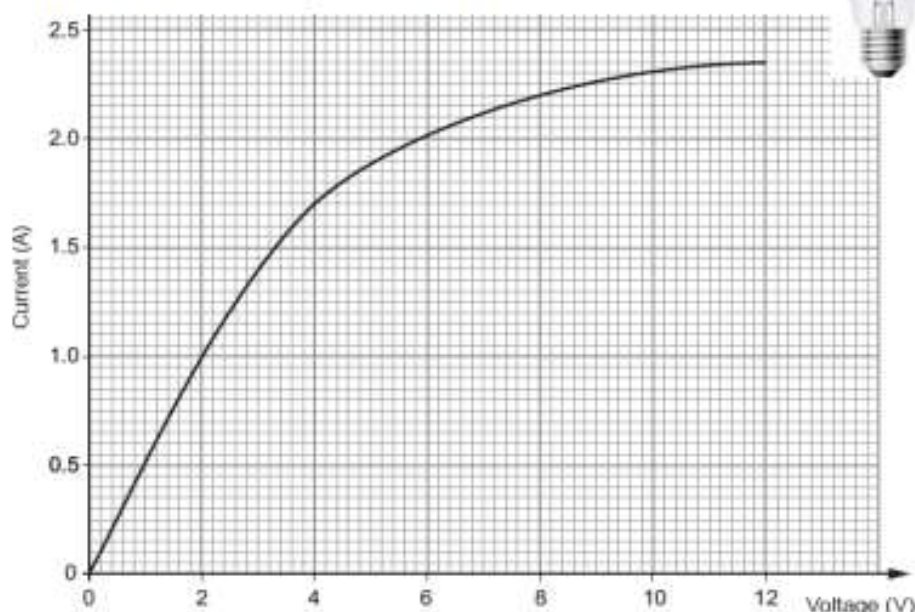
If the voltage remains constant then if the resistance of **resistor/wire doubles** then the **current will halve**. This relationship is **inversely proportional**.

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.

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

$$(i) \quad R = \frac{2.0}{1.0} = 2.00 \, \Omega$$

$$(ii) \quad R = \frac{12.0}{2.35} = 5.11 \, \Omega$$

Resistance graphs

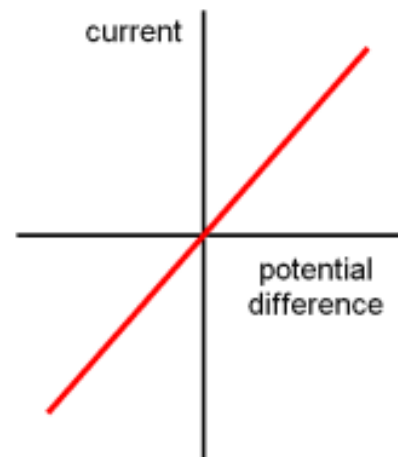
Current-potential difference graphs

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*.



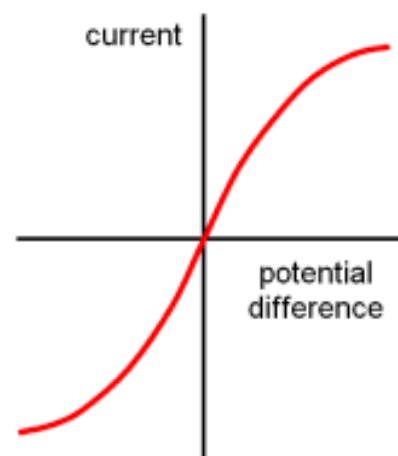
A graph with current on the y axis and voltage on the x axis. A diagonal line goes through the graph at 45 degrees

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.



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

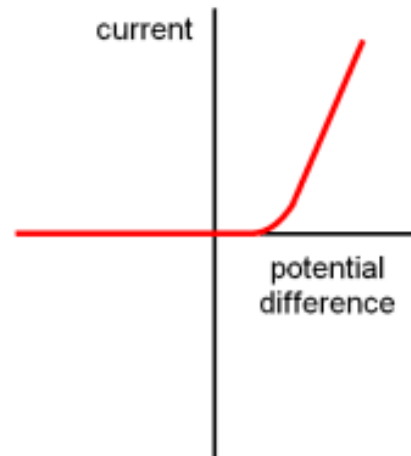
You should be able to recognise the graph of current against voltage for a diode.

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

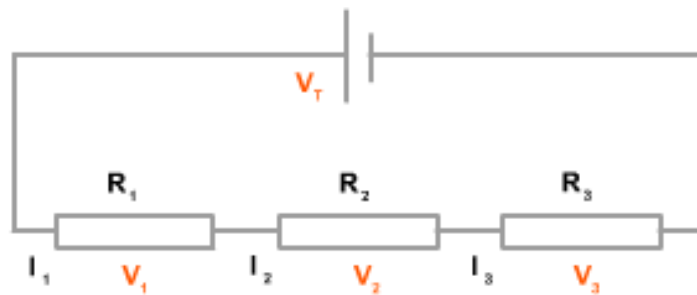
Resistor in series

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

☛ $I_1 = I_2 = I_3$

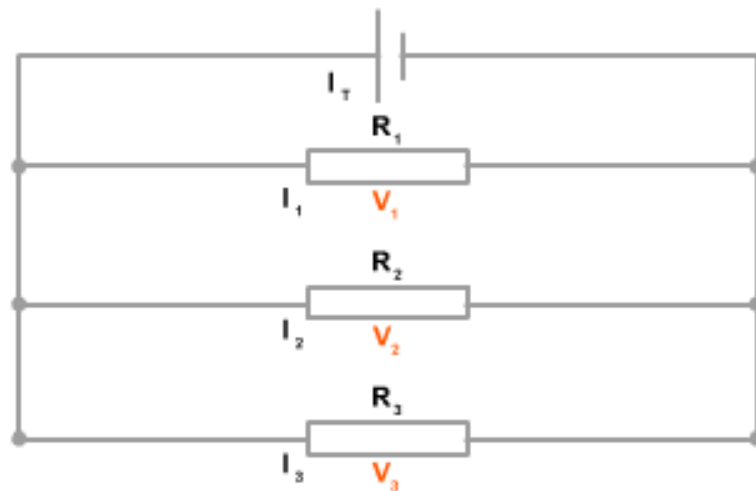
☛ $V_T = V_1 + V_2 + V_3$

And so, therefore, $R_T = R_1 + R_2 + R_3$

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 $1/R_T = 1/R_1 + 1/R_2 + 1/R_3$

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, $P = V \times I$**

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 : $\text{Power} = \text{Energy} \div \text{time}$

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



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

$$E = P \times t$$

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

Energy is measured in
Time is measured in
Power is measured in

Joules (J)
seconds (s)

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 ?

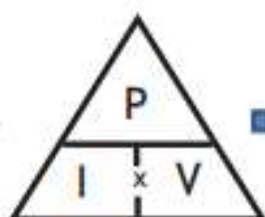
Answer : $E = P \times t = 3000 \times (3 \times 60) = 540\,000 \text{ J}$

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 : $I = P / V = 1200 / 240 = 5 \text{ Amps}$ (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

$$P = V \times I$$

$$V = I \times R$$

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

Power = current² x resistance

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

Resistance in Ω = 2 x 1000 = 2000 Ω

then,

$$\begin{aligned} \text{Power} &= \text{current}^2 \times \text{resistance} \\ &= 0.8^2 \times 2000 \\ &= 1280 \text{ W} \end{aligned}$$

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.

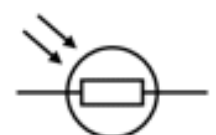


Thermistor

The LDR

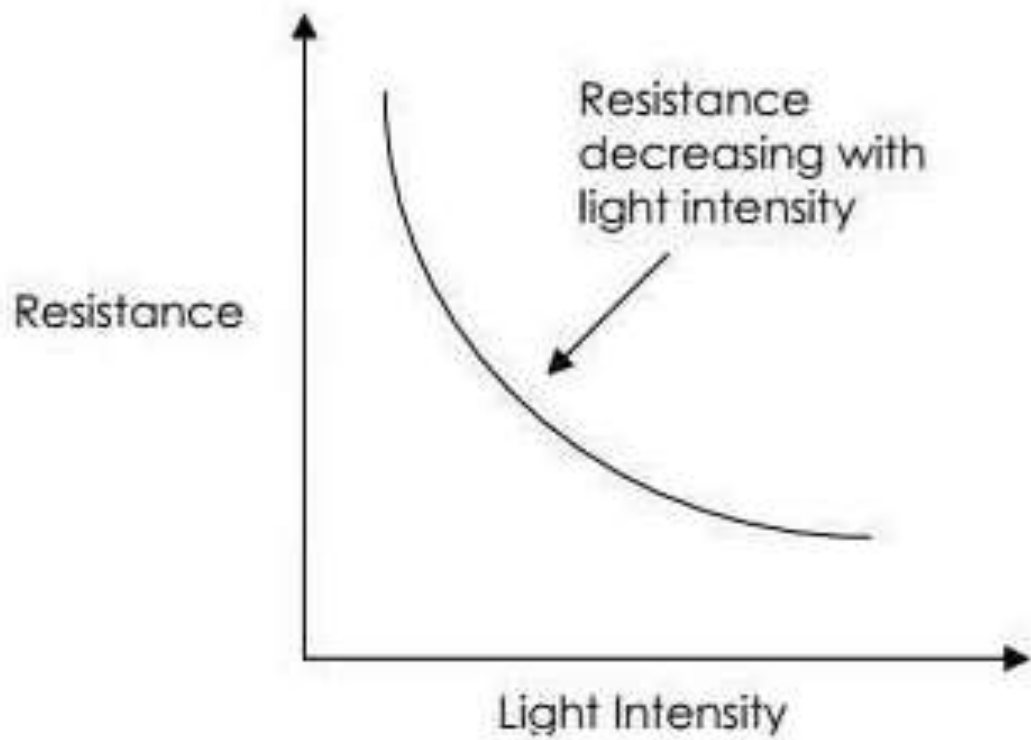
LDRs (light-dependent resistors) are used to detect light levels, for example, in automatic security lights. Their resistance decreases as the light intensity increases:

- 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.

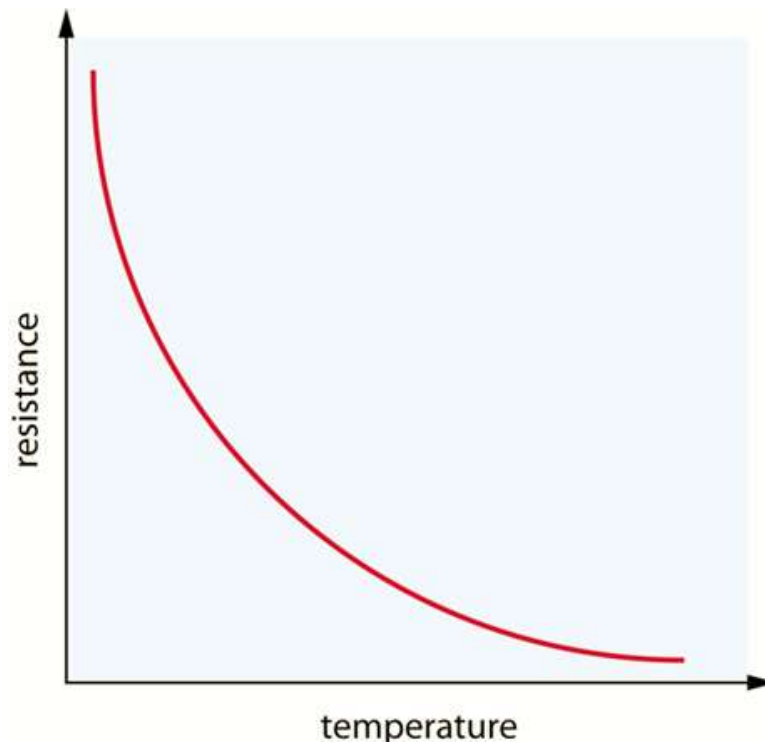


Light dependent resistor (LDR)

LDR graph



Thermistor graph

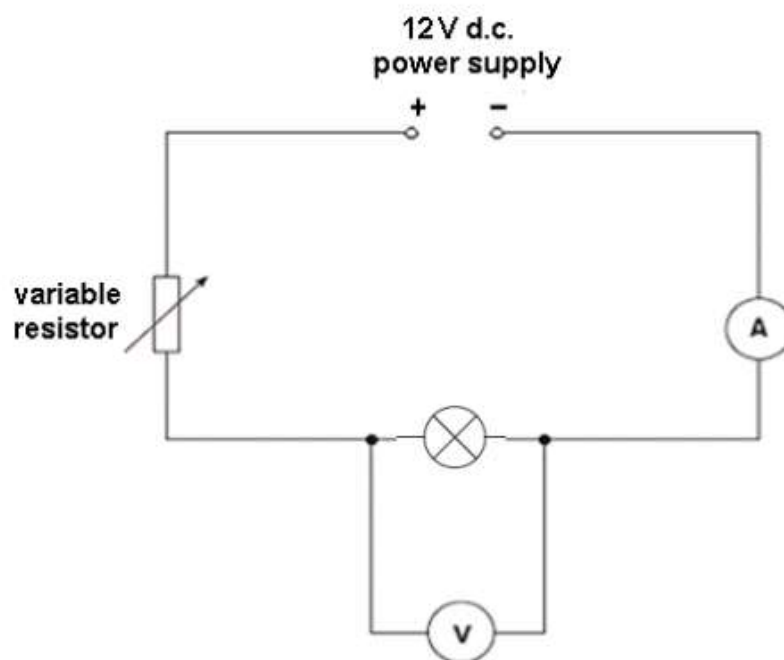


Specified Practical Work

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:

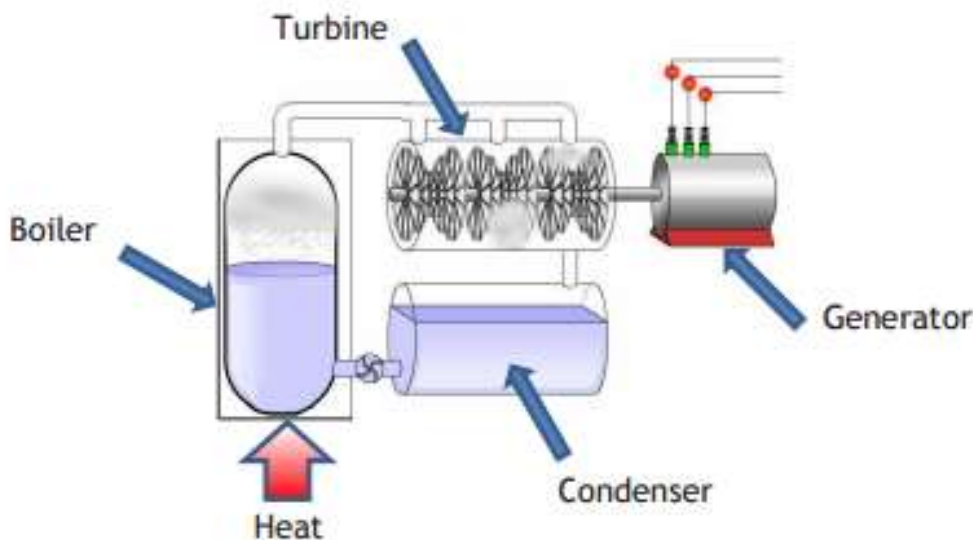
$$\% \text{ efficiency} = \frac{\text{energy [or power] usefully transferred}}{\text{total energy [or power] supplied}} \times 100$$

- (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:

$$\text{power} = \text{voltage} \times \text{current}; \quad P = VI$$

- (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

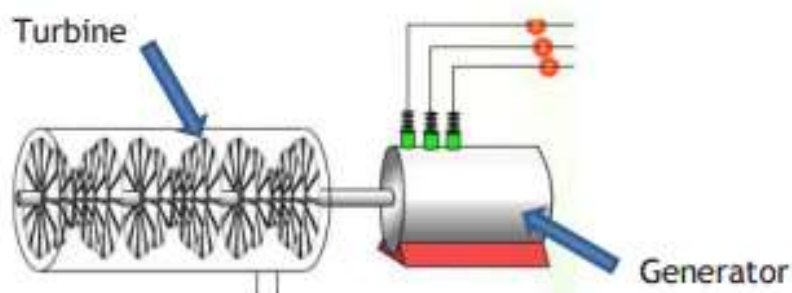
1. Shown below is a typical set-up for most power stations. The fuel is used to provide heat energy to water in a boiler. The water changes to steam which turns the blades of a turbine. The turbine is connected to a generator which then produces electricity.



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 (CO₂). CO₂ is a greenhouse gas that causes global warming.

Costs

One wind turbine

£80,000
BARGAIN??

Wylfa Nuclear power station

£2,000,000,000

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 = $1,000,000 \text{ W} \div 25,000 \text{ W} = 40$
Total cost = $40 \times £80,000 = £3.2 \text{ million per MW}$

Nuclear : Total commissioning cost is £2,000 million (£2 billion). Total electrical power produced is about 650 MW.

Therefore, Cost per MW = $£2,000 \div 650 = £3.1 \text{ million per MW}$

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” :

$$\text{Payback time (in years)} = \text{cost} \div \text{savings per year}$$

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.

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



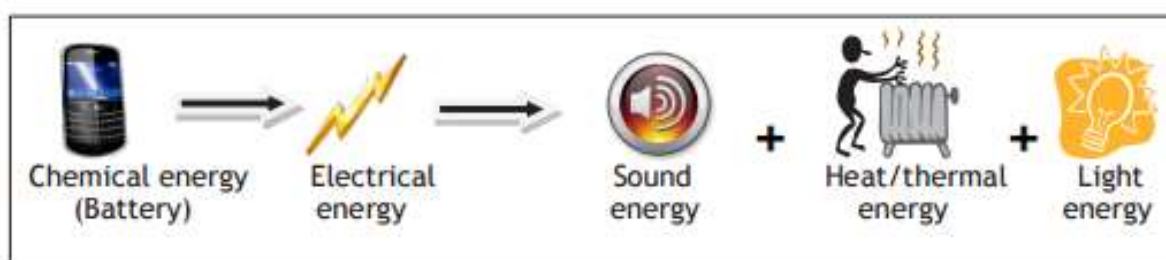
You will not be expected to remember data about different energy sources, only use what is given in the exam question.

See the example on the next page.

Energy Transfer

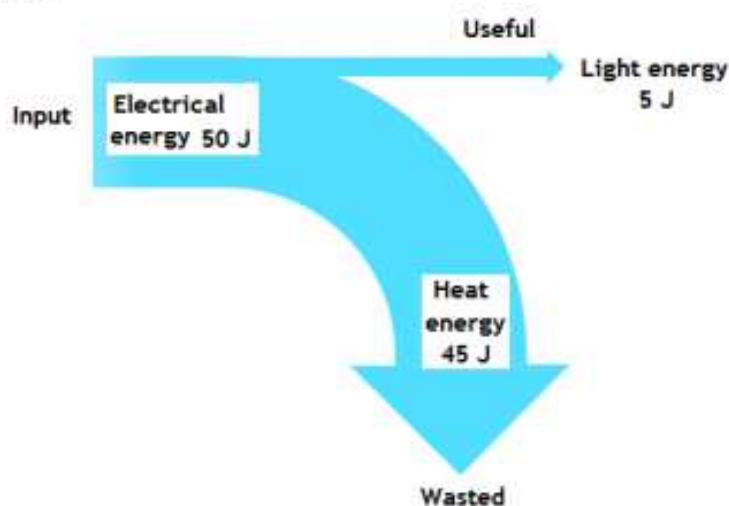
Type of energy	Example
Electrical	Into hairdryer.
Heat	Cooker.
Kinetic	Moving energy - car.
Sound energy	Speaker
Light energy	An object which emits light - LCD screen.
Chemical energy	Stored in food/battery.
Gravitational potential energy	Increases with height above ground - pump storage station.
Elastic 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: $50 \text{ J (input)} = 45 \text{ J} + 5 \text{ J (output)}$
- 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. $10 \text{ J} = 5 \text{ mm}$

Efficiency

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

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

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 current.

1. Heat energy is wasted in the cables

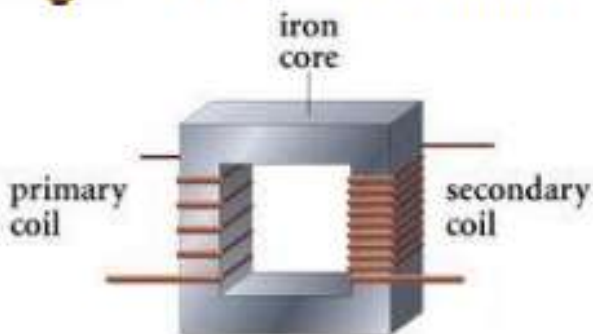
Typically, power stations produce electricity with a total current of about 10,000 Amps.

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 current, 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 ($20,000 \times 20 = 400,000 \text{ V}$), 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 output power. The equation "Power = current x voltage" ($P=I \times V$) can be used to calculate the effect on the current, when the voltage is changed.

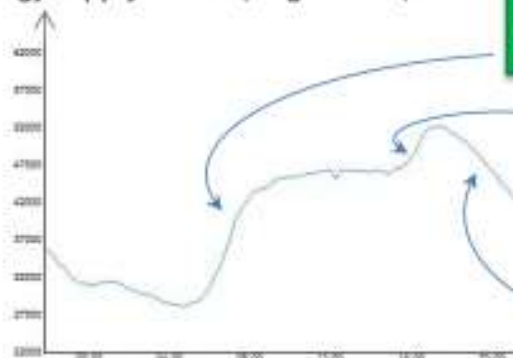
Transmitting electricity

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).



A surge in the morning when people wake up.

A surge in the evening at meal time.

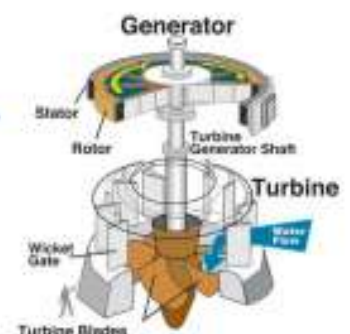
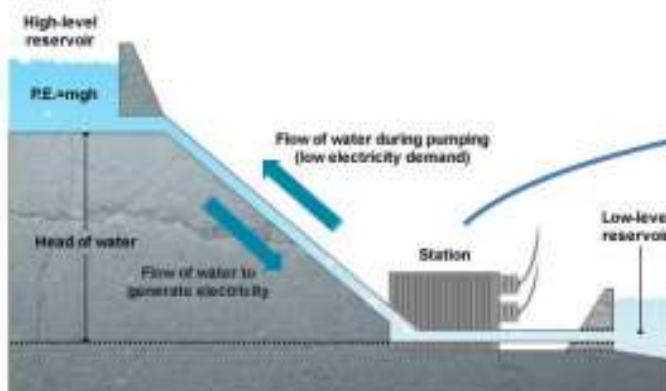
A drop when people are going to bed.

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.

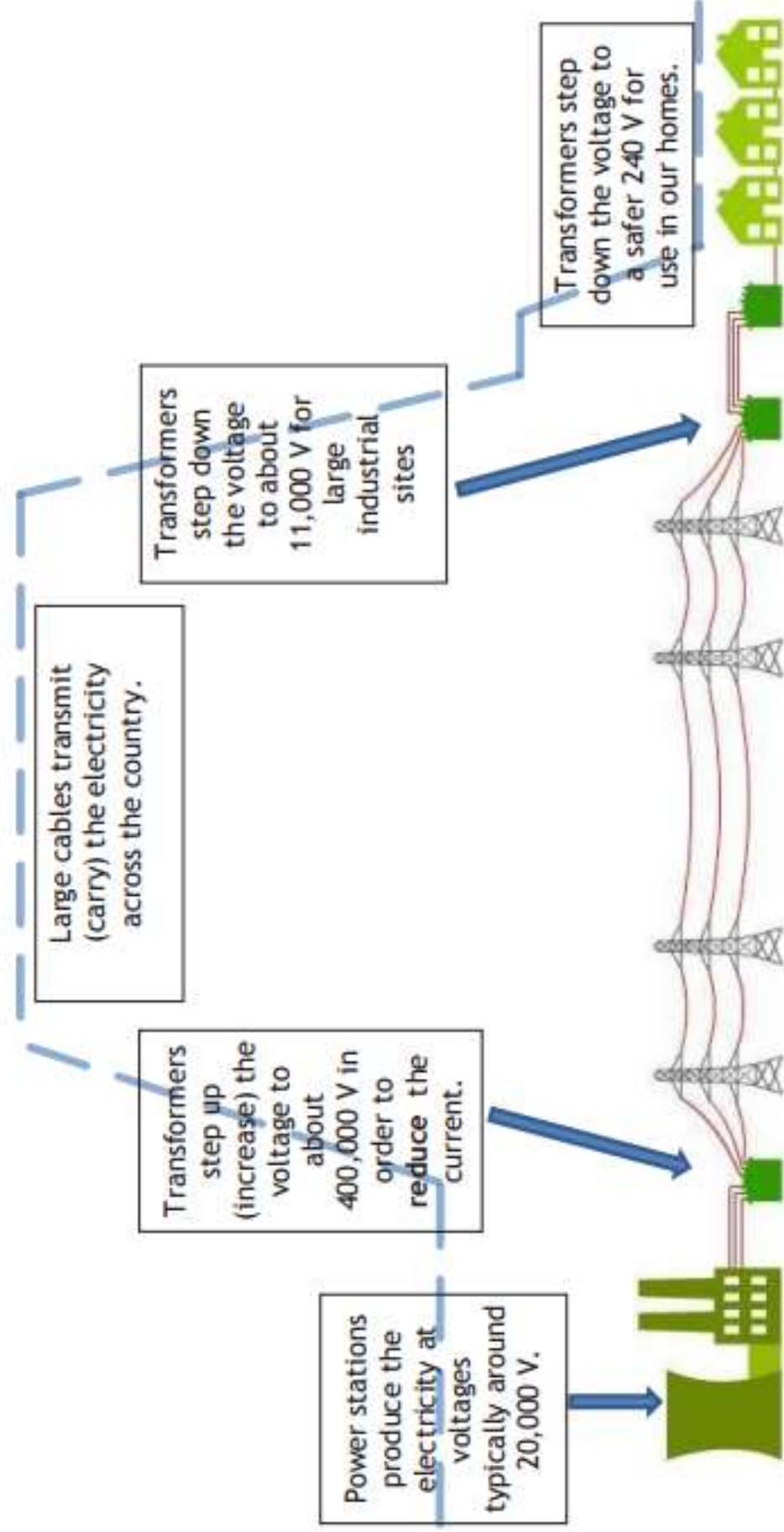
A fast-response hydroelectric power station (pump-storage)



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.)



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.

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.

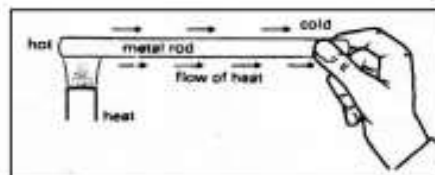
3 types of thermal transfer: Thermal energy can be transferred via conduction, convection and radiation.



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.

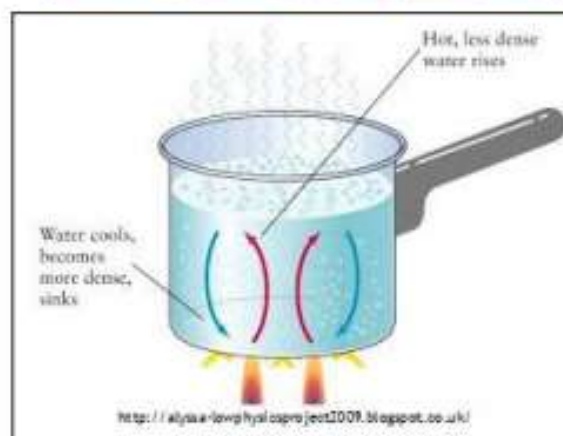
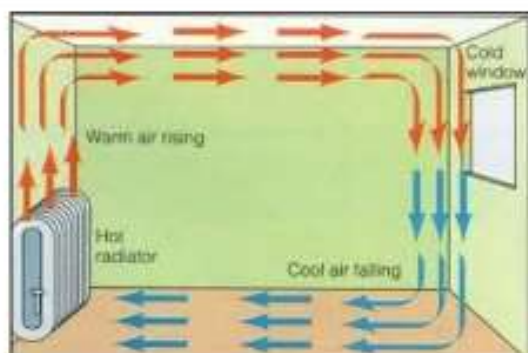


Convection: Heat flows by convection in **liquids** and **gases** only. Convection cannot occur in solids because the particles are fixed.

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.

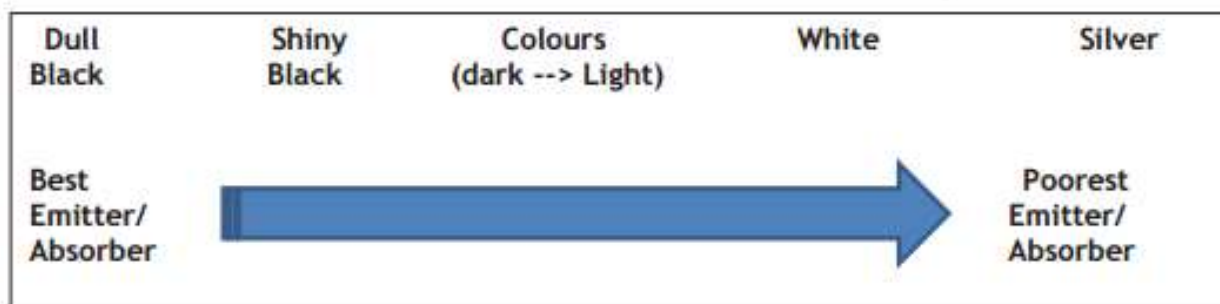
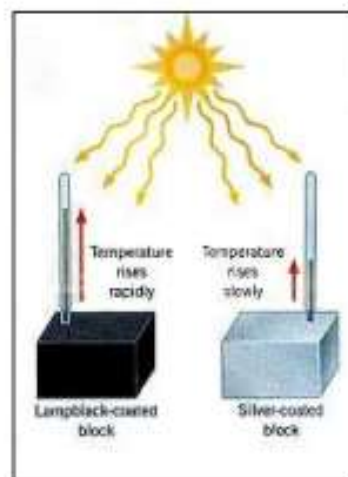


Thermal Radiation (infrared). Any hot object will emit thermal radiation in the form of infrared electromagnetic radiation.

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.

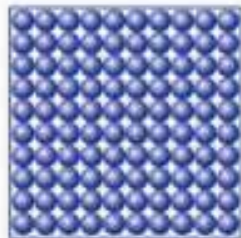


Density

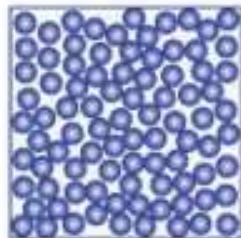
Density tells us how much mass of a certain material is contained within a certain volume.

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

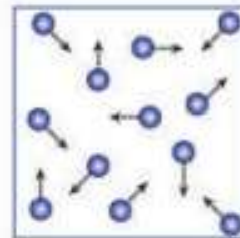
So, in general, solids have high density values whereas gases have very low values:



Solid



Liquid



Gas

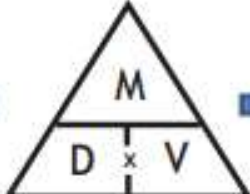
Here's the equation for calculating density :

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

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

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

→



→

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

$M = D \times V$

Example

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

Volume of the block = $l \times w \times h = 14 \times 4.5 \times 2 = 126 \text{ cm}^3$.

So, density of block, $D = \frac{M}{V} = \frac{315}{126} = 2.5 \text{ g/cm}^3$

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 .

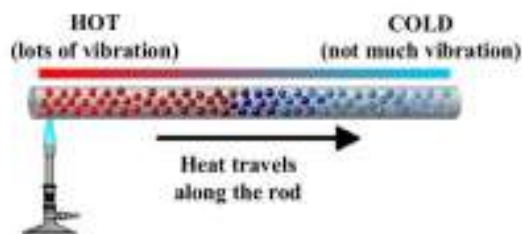
This is why a turbine driven by a certain volume of water is capable of generating more electricity than a turbine driven by the same volume of air. 1 m^3 of water weighs about 854 times the same amount of air.

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 $V/T = \text{constant}$, i.e. gases expanding at constant pressure).

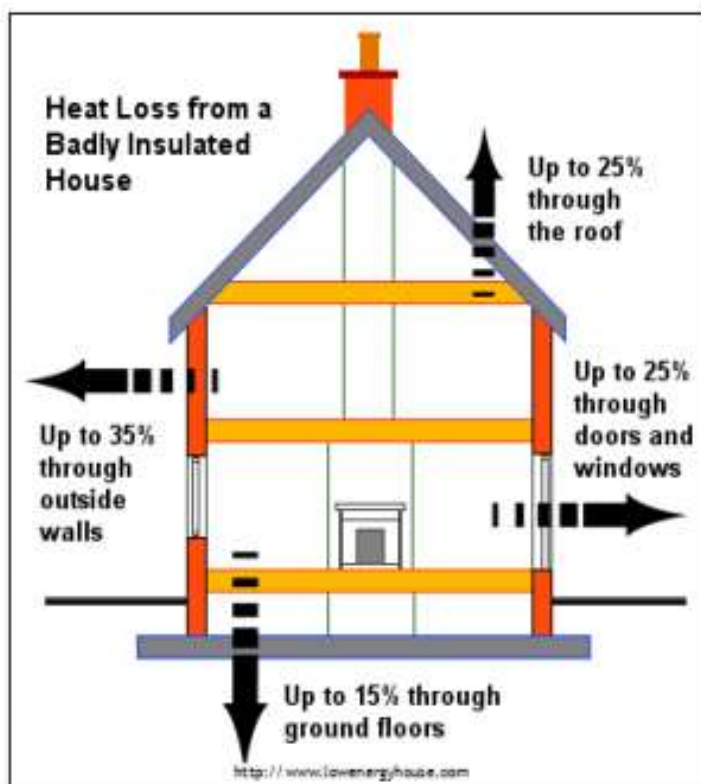
The fluid in this locality is now less dense than surrounding fluid, and so it rises, forming a **convection current**.



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. CO₂ 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	2 400	96	25

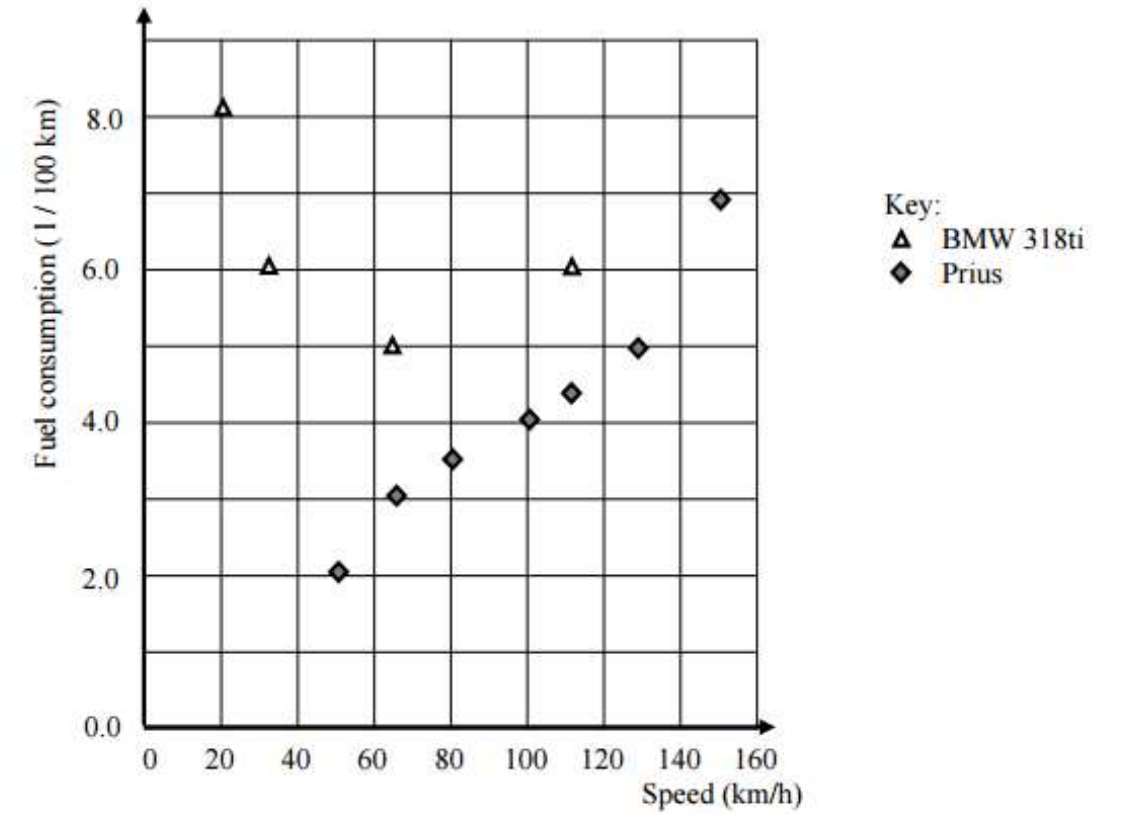
- (a) Complete the spaces in the last **two** columns of the table. [2]
- (b) Use information from the table opposite to advise the owner on how best to spend all the £3 200 on insulation. [6 QWC]

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 cm³ beaker
1 crystal of potassium manganate(VII)
10 cm³ 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

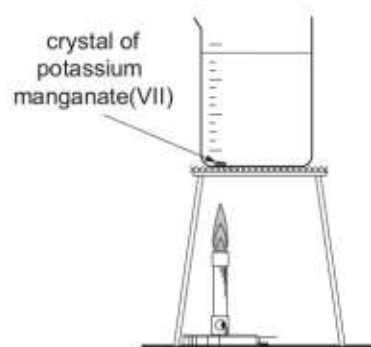
4 × metal rods
(aluminium, brass, copper and iron)
4 × drawing pins
Vaseline
tripod
Bunsen burner
heat proof mat
stopwatch

OR

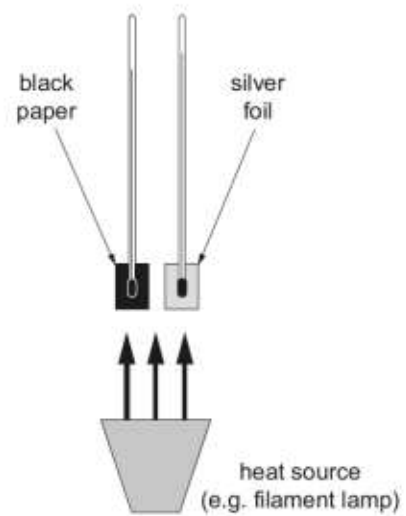
conductive ring
(aluminium, brass, copper and steel)
4 × wooden matches
Vaseline
clamp stand, clamp and boss
Bunsen burner
heat proof mat
stopwatch

Diagram of Apparatus

Convection Experiment

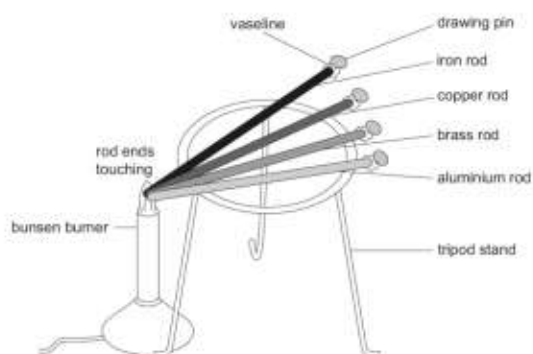


Radiation Experiment

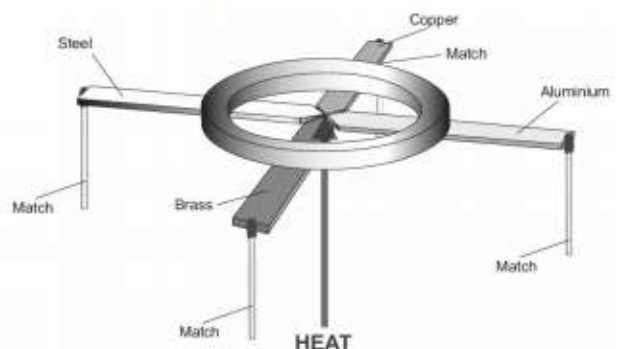


Conduction Experiment

EITHER **Metal Rods Experiment**



OR **Conductive Ring Experiment**



Method

Convection Experiment

1. Fill the beaker to $\frac{3}{4}$ 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

Metal Rods Experiment

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

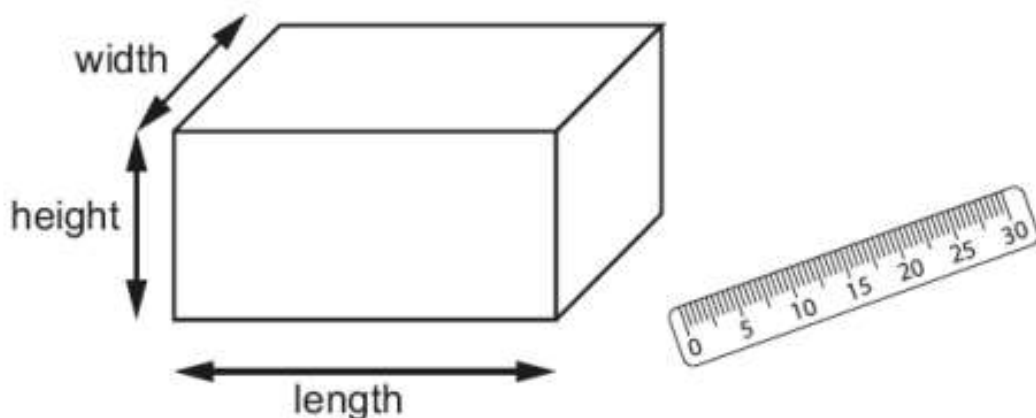
2 × regular shaped solids
2 × irregular shaped solids
30 cm ruler
50 cm³ measuring cylinder
water

Access to:

electronic balance ± 0.1 g

Measuring the density of a regular shaped solid

Diagram of Apparatus



Method

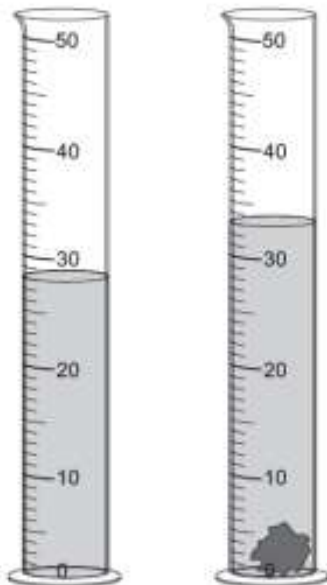
1. Record the mass of the solid.
2. Record the length, width and thickness of the solid using a ruler.
3. Repeat for cubes of different material.

Analysis

1. Calculate the volume of the cube from: $\text{volume} = \text{length} \times \text{height} \times \text{width}$.
2. Calculate the density in g/cm^3 .

Measuring the density of an irregular shaped solid

Diagram of Apparatus



Method

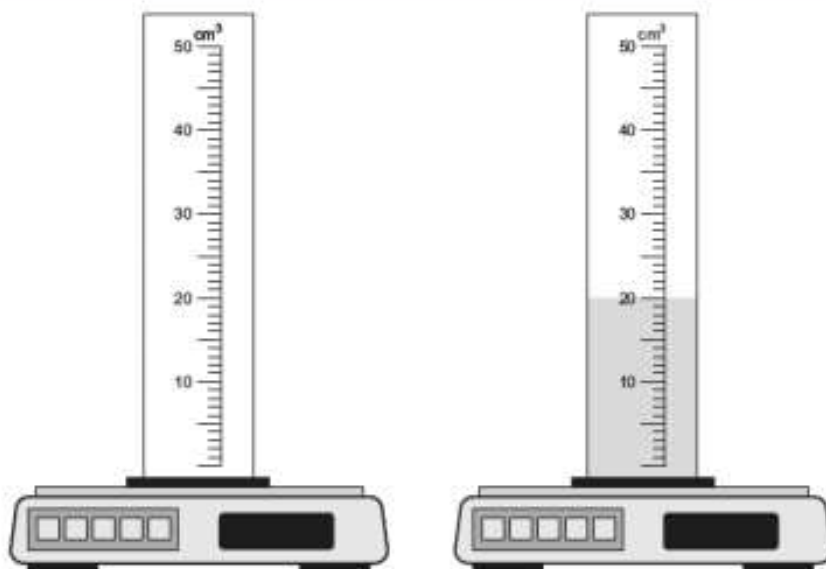
1. Record the mass of the solid.
2. Fill the measuring cylinder with water up to 20 cm^3 and record the volume.
3. Gently place the solid into the measuring cylinder and record the new volume.

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 $\rightarrow E = P \times t$ (see page 5 !!)

Normally, the units used are : $\begin{matrix} \text{J} & \text{W} & \text{s} \end{matrix}$ (Joules, Watts, and seconds)

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

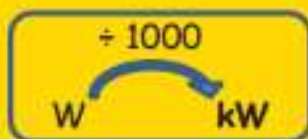
E	=	P	$\times$	t
(kWh)		kiloWatts		hours

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.



$$\text{Units used} = P \text{ (kW)} \times t \text{ (h)} = 0.85 \times 0.5 = 0.425 \text{ kWh}$$

$$\text{Cost} = 0.425 \times 12 \text{ pence} = 5.1 \text{ pence}$$

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	1 200	600	2	5 400	Average wind speed 4 m/s, (maximum 12 m/s)
Roof top photovoltaic cells (PV) of area 4 m ²	14 000		7	1 800	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)
 $3 \times 4 = 12 \text{ m}^2$ (1 mark)
- (c) Reduces CO₂ (1) which reduces the greenhouse effect / global warming (1) or Less SO₂ (1) which results in less acid rain (1) or Use less fossil fuels (1) so less extraction needed / less CO₂ / less SO₂ (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.

$$\text{Total energy input} = 2500 \times \text{time in seconds}$$

- 5.) Calculate the total energy from the kettle:

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

$$\text{Useful energy out} = 4200 \times \text{temperature rise}$$

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

Now we can find the efficiency of our kettle.

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

- 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 global 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 fluorescent 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!

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.

SciFile

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.



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.

Comparing labels

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!

SciFile

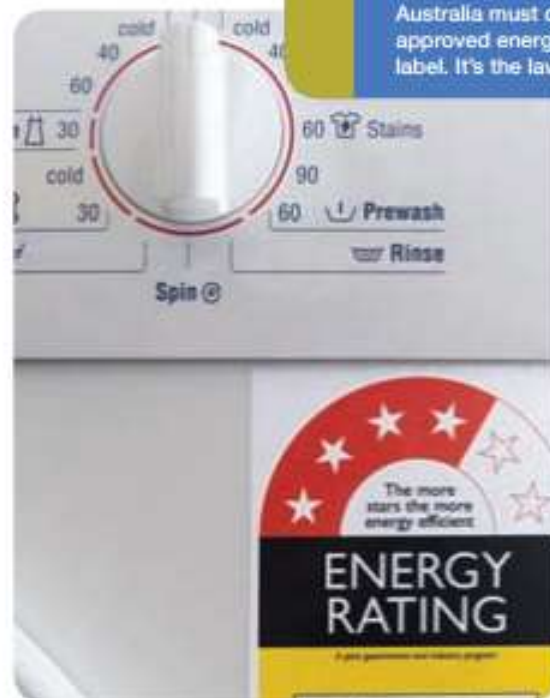


Figure 5.3.1

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.

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.

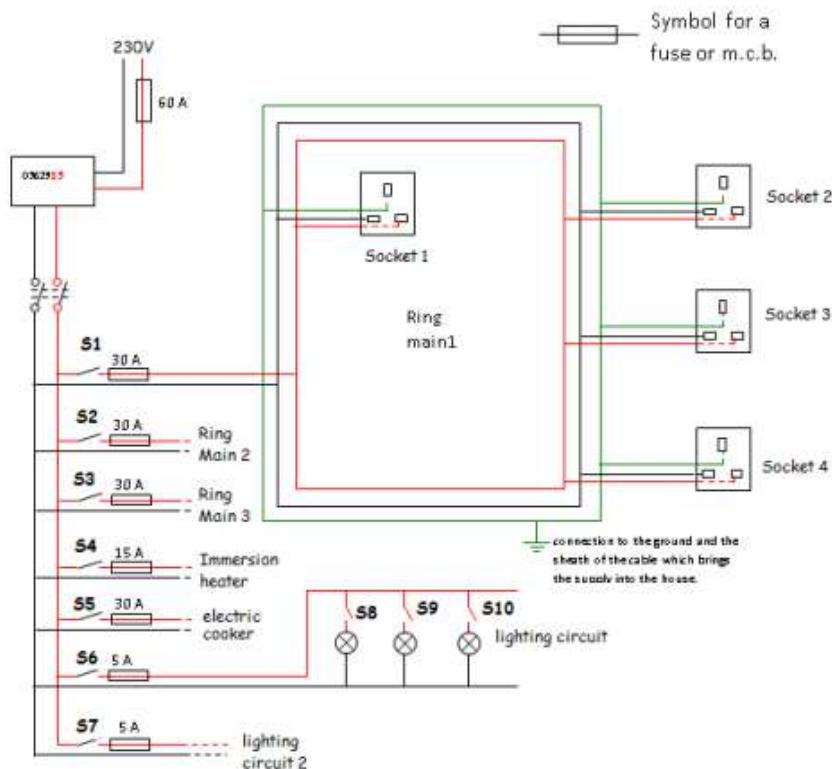


Figure 5.3.2

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= 230 V
2. Which switch would you use if you wanted to do maintenance work on ring main1? Answer = S1
3. What is the maximum power that could be supplied to the electric cooker?

$$\begin{aligned}
 P &= V \times I \\
 &= 230 \times 30 \\
 &= \underline{6900 \text{ W}}
 \end{aligned}$$

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.

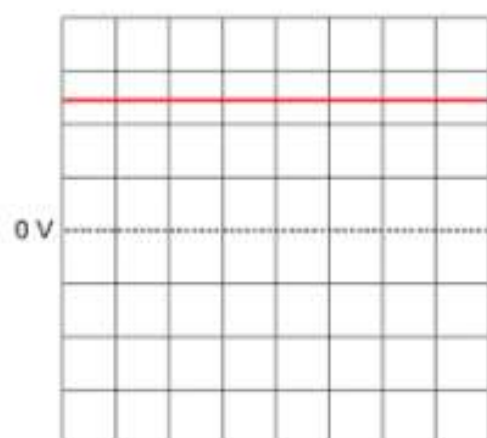
Total current for all bulbs = $0.05 + 0.05 + 0.05 = 0.15 \text{ A}$

$$\text{Power} = \text{voltage} \times \text{current} = 230 \times 0.15 = \underline{34.5 \text{ W}}$$

Direct current and alternating current

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

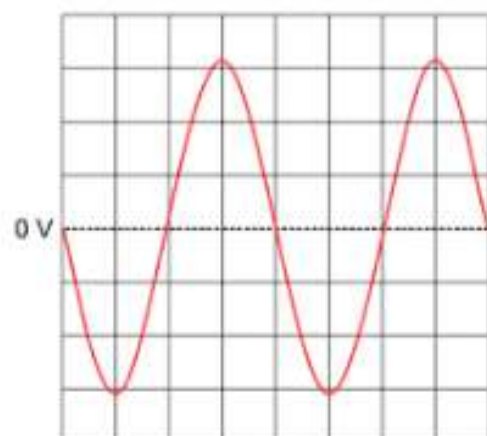
Direct current



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.

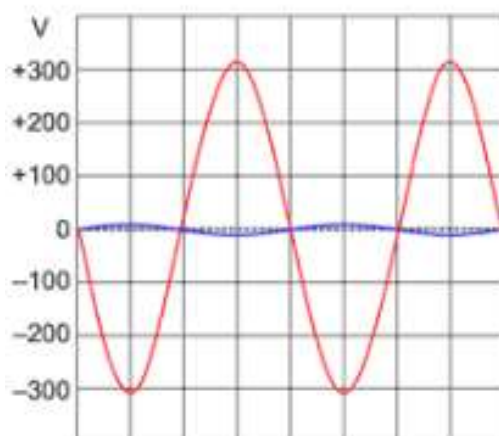
Alternating current



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

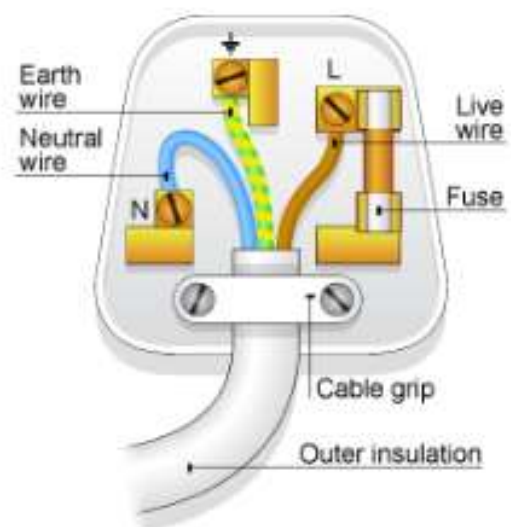
colour	wire
blue	neutral
brown	live
green and yellow stripes	earth

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

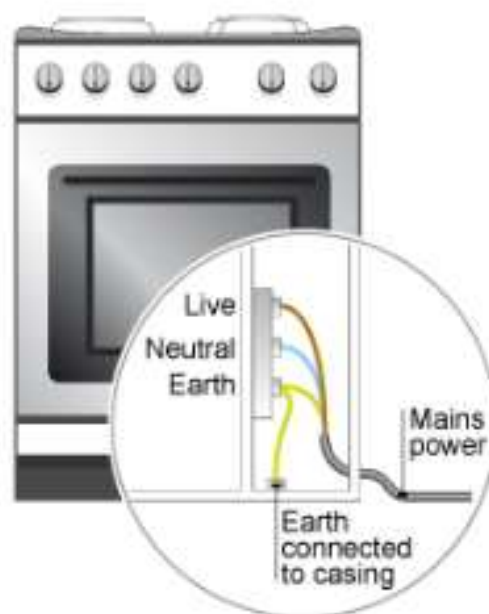
Earthing

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

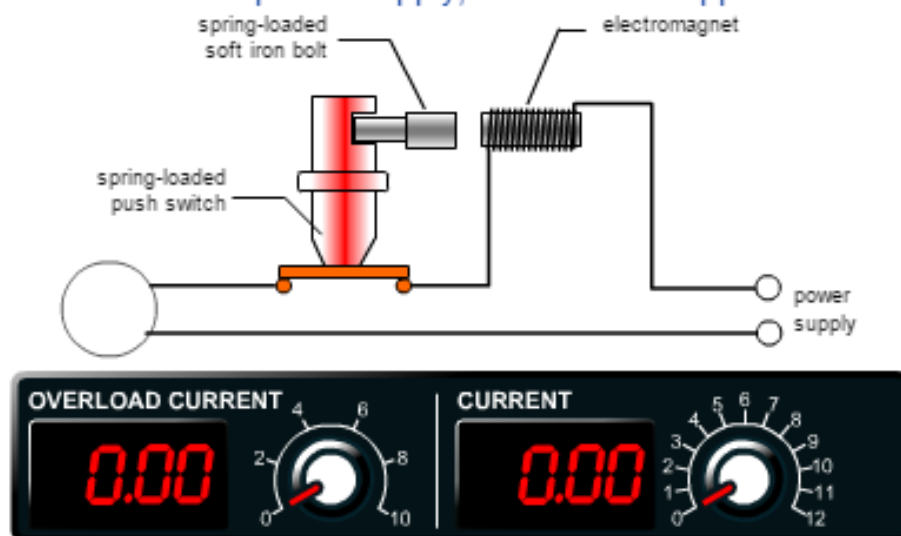
The circuit breaker does the same job as the fuse, but works in a different way. A spring-loaded push switch is held in the closed position by a spring-loaded soft iron bolt. An electromagnet is arranged so that it can pull the bolt away from the switch. If the current increases beyond a set limit, the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

[Help](#)

Set the required overload current, and then increase the current from the power supply, to see what happens.



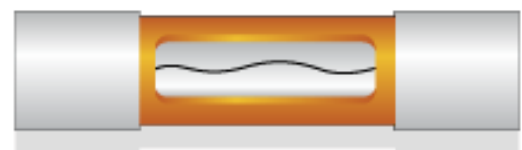
The fuse

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.

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:

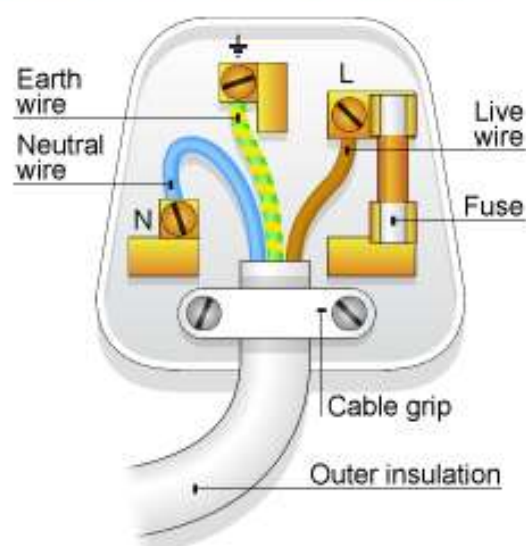
- ✚ if the device works at 3A, use a 5A fuse
- ✚ if the device works at 10A, use a 13A fuse

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



A 13A fuse with a low melting point wire

Live, neutral and earth wires

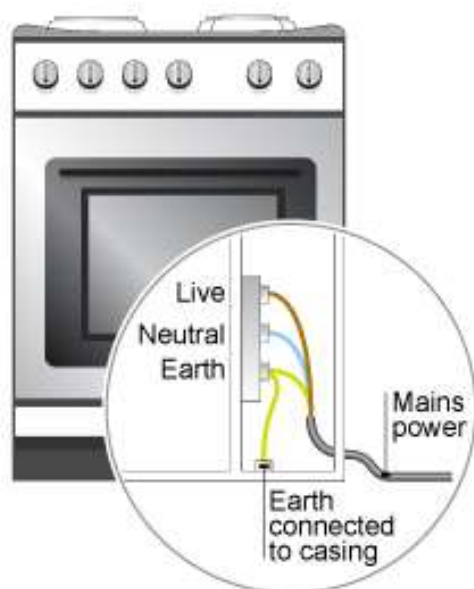


The inside of a plug

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**.



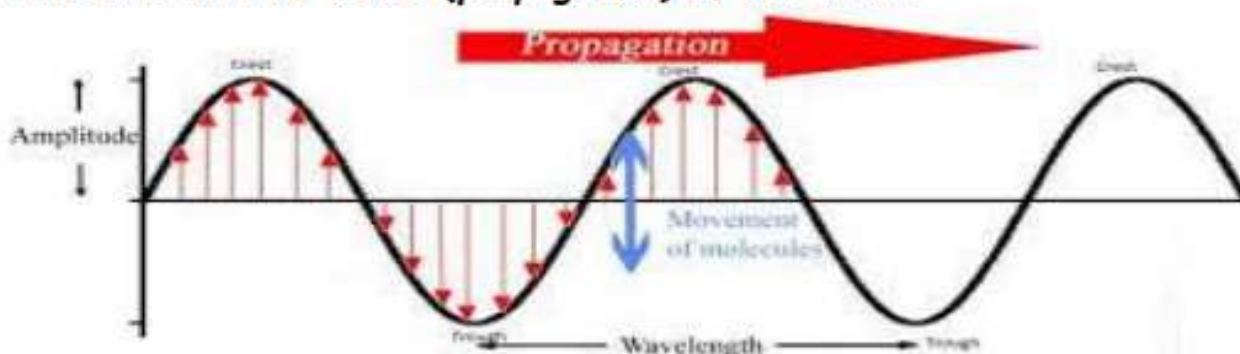
Unit 1.5 – Features of Waves

- (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 $\times$ 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

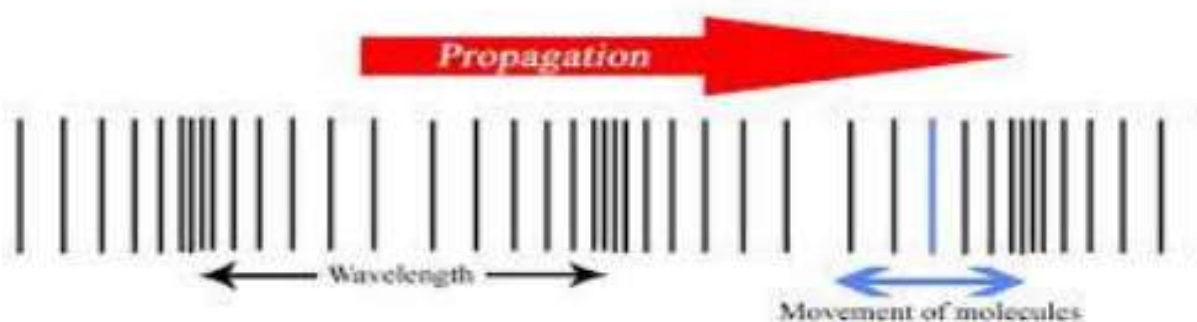
- Investigation of the speed of water waves

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.

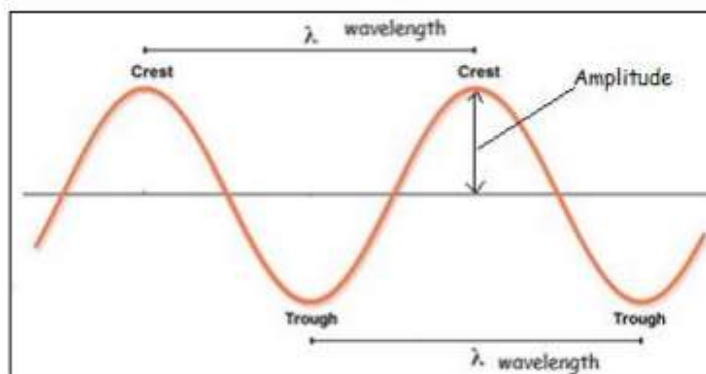


Examples: Sound waves, P-waves

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

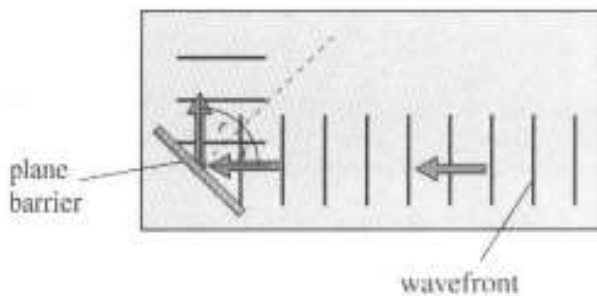
Characteristics of waves. (what can we measure)

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



Characteristics	What is it?	Units
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 1 waves 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.

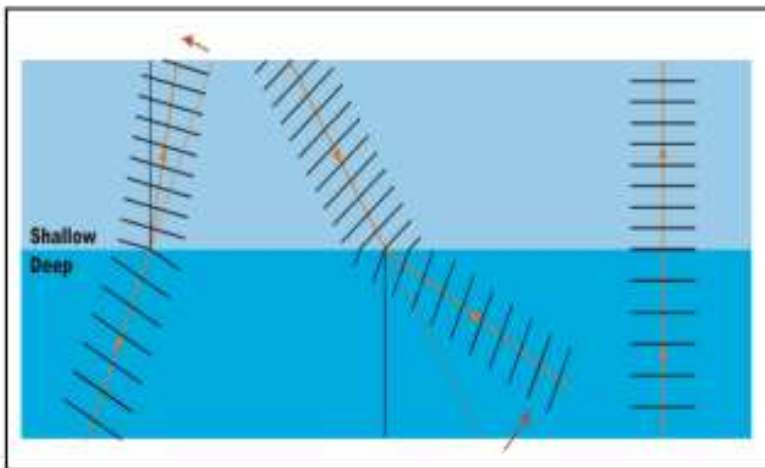
Reflection. As the waves strike a plane (flat) barrier they are reflected. This is very similar for a beam of light reflecting on a plane mirror. If a curved (concave) barrier such as a satellite dish is used, the waves can be made to converge (concentrate) at a point. The angle of incidence and reflection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



Reflection on a satellite dish.

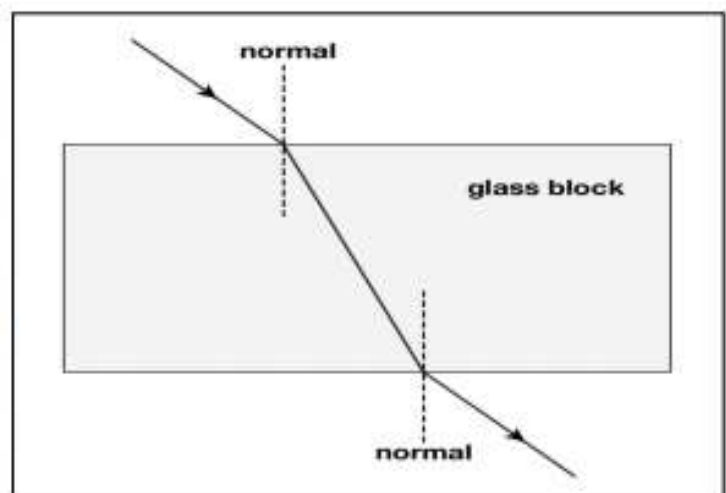


Refraction: Refraction is the change in direction of a wave at the boundary between two materials. This is caused by a change in speed.



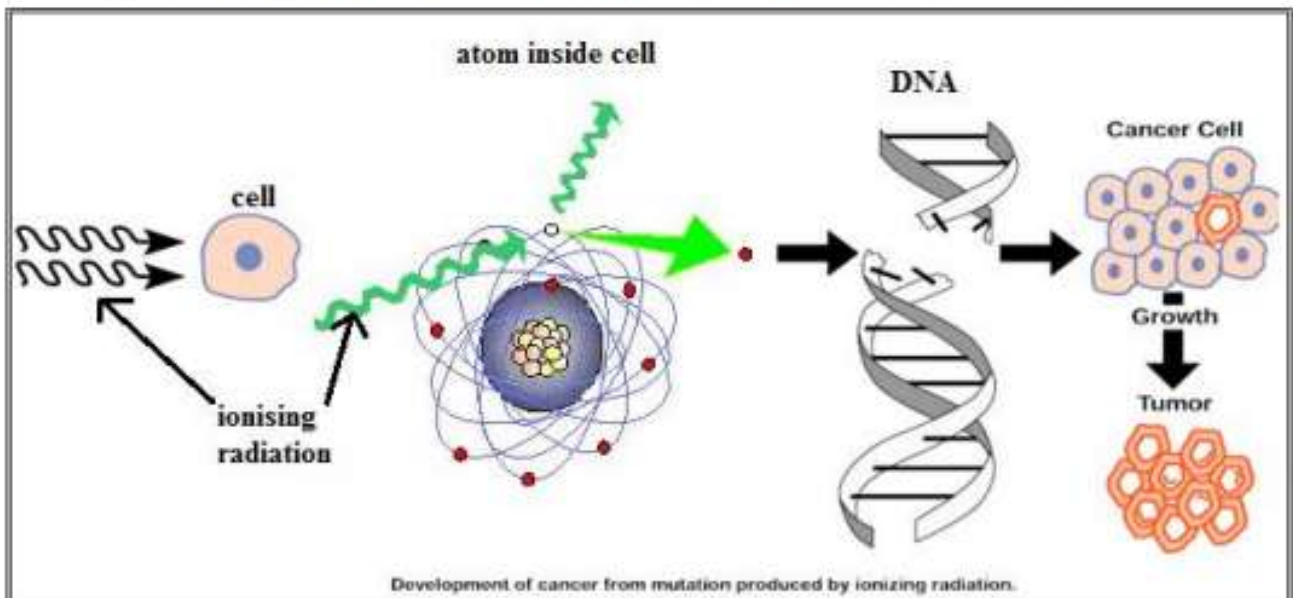
Water. This occurs when water waves pass between deep and shallow water. The waves move more slowly in shallow water. The *frequency of the waves remain constant* and so the wavelength decreases. When the waves move from shallow to deeper water, their speed increase and they change direction away from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

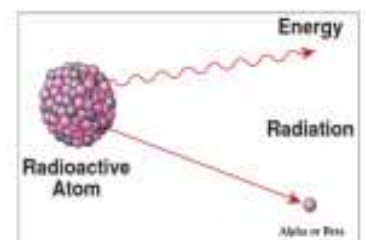


Ionising radiation include: alpha, beta, gamma, x-rays and ultraviolet.

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.

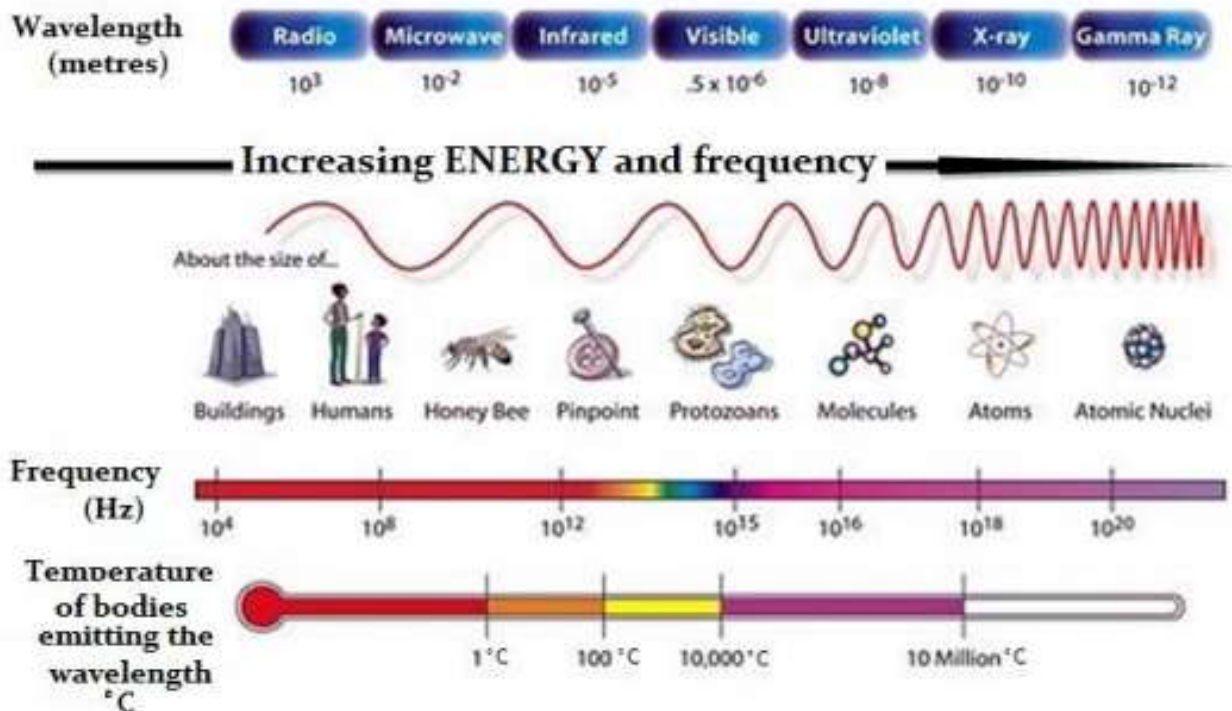
The 3 types of radioactive emissions from a nucleus.

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 electromagnetic spectrum



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.

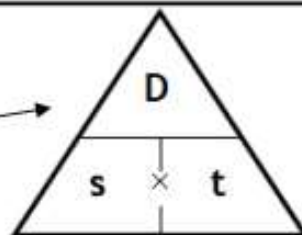
Uses of the em spectrum.

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.

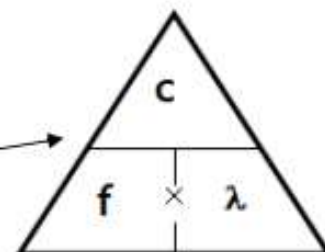
The speed of a wave can be calculated in 2 ways.

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



$$2. \text{ wave speed} = \text{frequency} \times \text{wavelength}$$

$$c = f \lambda$$



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).

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

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 2nd equation since speed and wavelength are given.

Speed = frequency x wavelength

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

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

$$150,000,000 \text{ km} \times 1000 = 150,000,000,000 \text{ m or } 1.5 \times 10^{11} \text{ m}$$

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

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

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

Satellites.

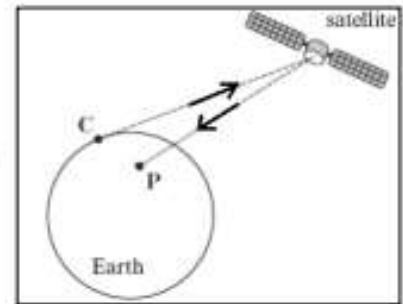
Communication satellites need to be in a **geosynchronous orbit** (36,000 km high) because Satellite needs to be above a fixed point on the Earth so satellite dishes (e.g. sky dish) do not have to be moved.

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.

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

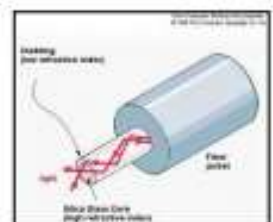


Method 2, optical fibres: The distance from Wales to Italy is about 2000 km = 2×10^6 m.

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?

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

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



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

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.

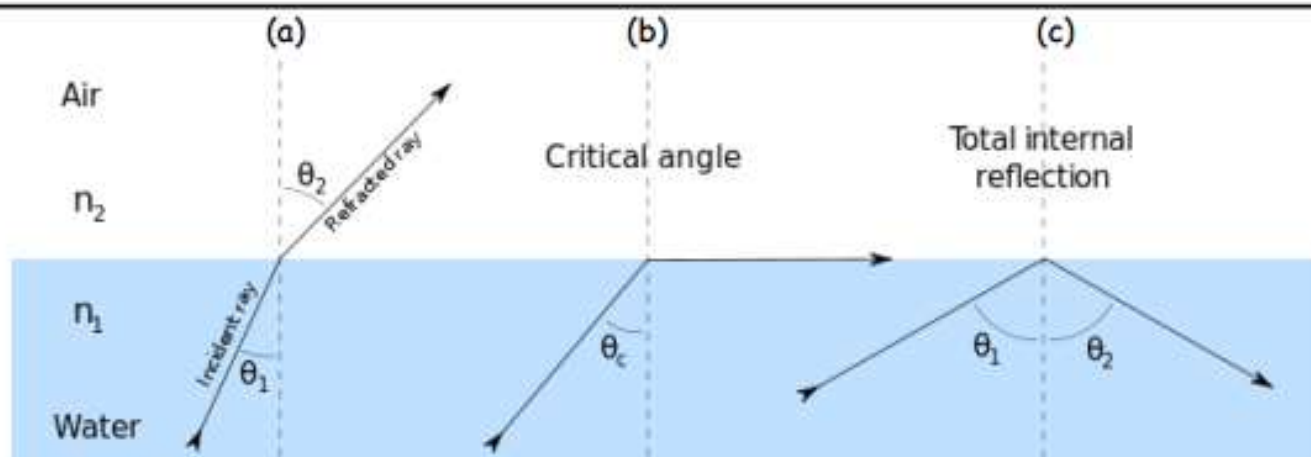
Risk Assessment

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

Unit 1.6 – TIR of waves

- (a) the conditions for total internal reflection of light
- (b) how optical fibres rely on total internal reflection for their operation
- (c) comparison of the advantages and disadvantages of optical fibres and geosynchronous / geostationary satellites for long distance communication
- (d) the use of optical fibres for remote imaging, including endoscopic medical examinations and a comparison of endoscopy with CT scans for obtaining medical information

Total internal reflection



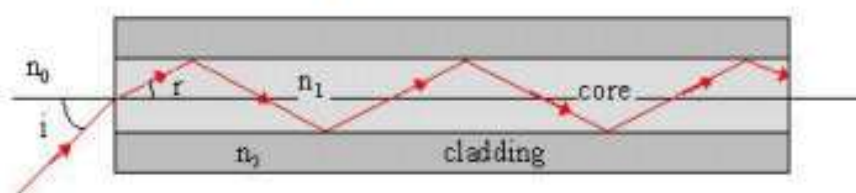
This phenomenon occurs when light moves from a more optically dense material (e.g. water) to a less optically dense material (e.g. air) causing a change in speed.

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.

Endoscopes

Optical fibres can be manufactured to be extremely thin (thinner than a human hair), and they are very flexible. This makes them very useful for transmitting communications (the signals travel at the speed of light in glass) and for use in medical endoscopes. A medical endoscope generally has two sets of **optical** fibres inside it. One set of fibres takes light from a

source down through the endoscope and another set picks up the light that is reflected off the inside of the body and transmits it back up the endoscope, so it can be displayed on a screen for the doctor.

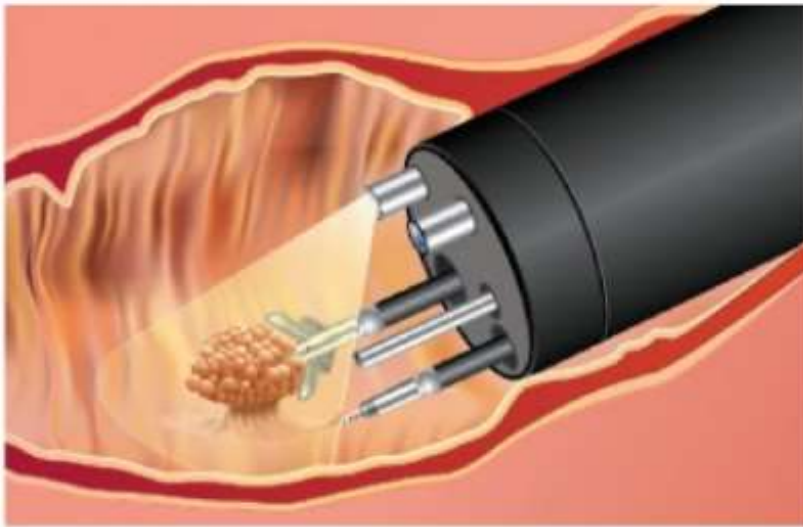


Figure 6.5 The optical fibres and other tools inside an endoscope.

Endoscopes allow 'keyhole' surgery to be performed. Endoscopes can be inserted into the body through the mouth or the anus, allowing good access to the digestive system, without making any surgical incisions. Other parts of the body can be accessed by making a small 'keyhole-sized' incision in the skin and the endoscope tube is passed into the body cavities or the blood stream. Endoscopy has several advantages over other surgical and medical imaging techniques, such as conventional surgery and X-ray scans:

- Endoscopy uses existing body orifices such as the mouth and the anus, or tiny incisions in the skin. Recovery times from these procedures are very quick, and risk of infection is kept to a minimum.
- No ionising radiation is used, reducing the chances of damage to non-affected cells.
- Biopsies (small tissue samples) can be taken by the probes at the end of the endoscope, allowing cell and tissue samples to be analysed by biomedical scientists.
- Real-time, close-up, colour images or video of internal body features can

- Fibre-optic lines use less energy.
- They need fewer boosters.
- There is no cross-talk (interference) with adjoining cables.
- They are difficult to bug.
- Their weight is lower, so they are easier to install.

Optical fibres or microwaves?

Both **optical** fibres (using the infra-red part of the electromagnetic spectrum) and **satellite** communications (using microwaves) are used for TV broadcasts (and international phone calls). It takes time for the signals to travel from an Earth station up to one of the satellites and back again (Figure 6.8). Let's compare the time delay in sending a signal from A to B.

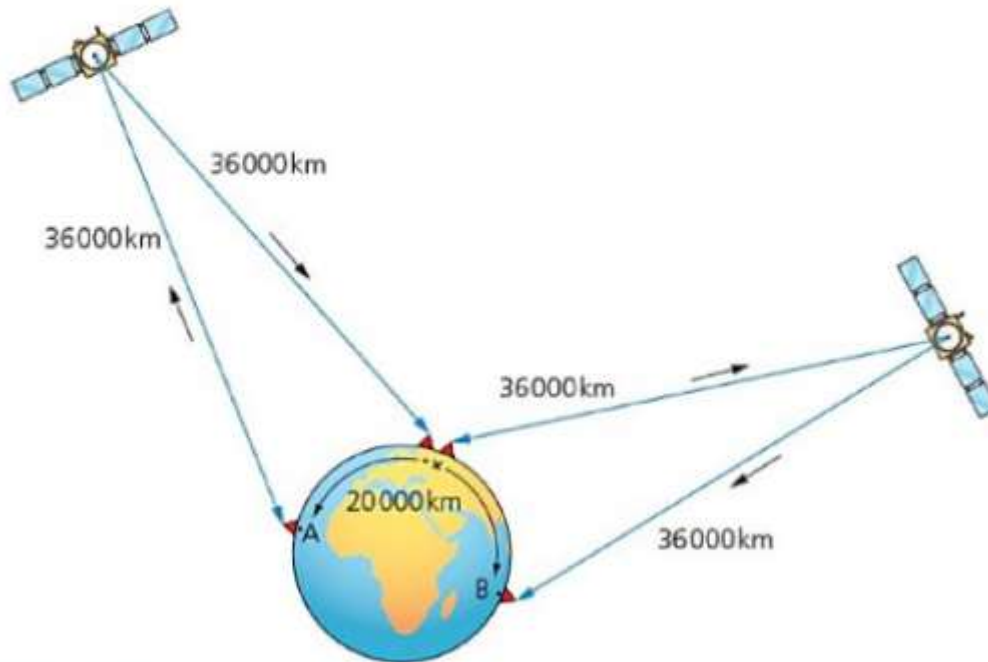


Figure 6.8 The satellite signal has much further to travel.

The satellites orbit at a height of 36 000 km. Therefore, the path length is $4 \times 36\,000\text{ km}$, or 144 000 km. This is for studio-to-studio communication via **satellite**. Use the following formula:

$$\text{speed (km/s)} = \frac{\text{distance travelled (km)}}{\text{time taken (s)}}$$

Rearranging:

$$\text{time taken (s)} = \frac{\text{distance travelled (km)}}{\text{speed (km/s)}}$$

Put the numbers in:

$$\text{time taken (s)} = \frac{144\,000 \text{ km}}{300\,000 \text{ km/s}} = 0.5 \text{ s (approx)}$$

An outside broadcast might increase the journey to 200 000 km, making the time for travel about 0.7 s. This time delay on news broadcast or telephone conversations is quite noticeable and you may well have observed this effect on your television. With **optical** fibres connecting the two studios, the distance travelled may be only 20 000 km, and infra-red waves travel at 200 000 km/s in **optical** fibres:

$$\text{time delay (s)} = \frac{20\,000 \text{ km}}{200\,000 \text{ km/s}} = 0.1 \text{ s (approx)}$$

The time delay with **optical** fibres is only 0.1 s, which is much less noticeable.

Will **optical** fibres take over?

Optical fibres can handle a huge number of voice and data calls. Because of their greater information capacity, no noticeable time delay and no need for repeater stations, there is a worldwide shift towards using **optical** fibres for long-distance applications. However, microwaves and satellites will never be replaced by them. Microwave links often take over optical-fibre traffic when the cable is being repaired.

Chapter summary

- Light (and other forms of waves) undergo total internal reflection if the light crosses a boundary from a medium where it is travelling slowly into a medium where it is travelling faster, at an angle of incidence greater than the critical angle for the boundary.
- **Optical** fibres rely on total internal reflection for their operation
- **Optical** fibres using infra-red waves, and geosynchronous satellites using radio waves or microwaves, can be used for long-distance communication. **Optical** fibres can carry a large number of signals and have shorter time delays than **satellite** communications, but require a fixed connection, unlike **satellite** communications.
- **Optical** fibres can be used for endoscopic medical examinations. Endoscopes produce high quality close-up, real-time images and biopsies can be taken. Endoscopy is non-ionising and does not damage non-affected cells.

In an answer to a recent exam question, a candidate wrote: "A *SINGLE* geostationary satellite stays in the same place and is the only way of relaying all electromagnetic waves around the world."

Explain, in detail, what is wrong with the above statement.

[6 QWC]

Answer:

A geostationary / geosynchronous satellite orbits the Earth in 24 hours – the same time as the rotation period of the Earth. It therefore stays above the same point on the Earth so that ground satellite dishes do not have to be moved. A minimum of three satellites are needed to relay messages around the world. They relay only microwaves which carry TV, telephone and other signals. Signals can also be relayed along optical fibres which transfer via coded infra-red signals and radio waves can be reflected off the atmosphere.

What is a computed tomography (CT) scan?



Source: Terese Winslow

The term "computed tomography", or CT, refers to a computerized x-ray imaging procedure in which a narrow beam of x-rays is aimed at a patient and quickly rotated around the body, producing signals that are processed by the machine's computer to generate cross-sectional images—or "slices"—of the body. These slices are called tomographic images and contain more detailed information than conventional x-rays. Once a number of successive slices are collected by the machine's computer, they can be digitally "stacked" together to form a three-dimensional image of the patient that allows for easier identification and location of basic structures as well as possible tumors or abnormalities.

How does CT work?

Unlike a conventional x-ray—which uses a fixed x-ray tube—a CT scanner uses a motorized x-ray source that rotates around the circular opening of a donut-shaped structure called a gantry. During a CT scan, the patient lies on a bed that slowly moves through the gantry while the x-ray tube rotates around the patient, shooting narrow beams of x-rays through the body. Instead of film, CT scanners use special digital x-ray detectors, which are located directly opposite the x-ray source. As the x-rays leave the patient, they are picked up by the detectors and transmitted to a computer.

Each time the x-ray source completes one full rotation, the CT computer uses sophisticated mathematical techniques to construct a 2D image slice of the patient. The thickness of the tissue represented in each image slice can vary depending on the CT machine used, but usually ranges from 1-10 millimeters. When a full slice is completed, the image is stored and the motorized bed is moved forward incrementally into the gantry. The x-ray scanning process is then repeated to produce another image slice. This process continues until the desired number of slices is collected.



Are there risks?

CT scans can diagnose possibly life-threatening conditions such as hemorrhage, blood clots, or cancer. An early diagnosis of these conditions could potentially be life-saving. However, CT scans use x-rays, and all x-rays produce ionizing radiation. Ionizing radiation has the potential to cause biological effects in living tissue. This is a risk that increases with the number of exposures added up over the life of an individual. However, the risk of developing cancer from radiation exposure is generally small.

Children are more sensitive to ionizing radiation and have a longer life expectancy and, thus, a higher relative risk for developing cancer than adults. Parents may want to ask the technologist or doctor if their machine settings have been adjusted for children.

Endoscopy uses optical fibres and CT scans use X-rays. Endoscopy is used to investigate specific areas of the body and it is less harmful than CT scans. CT scans are used to generate more overall images of the body and are a higher risk than endoscopes. CT scans are 3D.

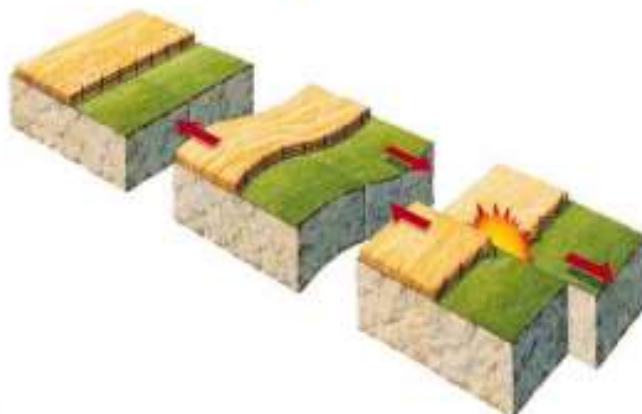
Unit 1.7 – Seismic Waves

- (a) the properties of seismic P waves, S waves and surface waves, in terms of their nature, speed and ability to penetrate different materials
- (b) the fact that P waves are longitudinal and S waves are transverse
- (c) simplified seismic records, to allow for the identification of the lag time between the arrival of the P and S waves to occur and to use the seismic records from several stations to locate the epicentre of an earthquake.
- (d) the path of P and S waves through the Earth (the dependence of the speed of seismic waves on the density and stiffness of the material will not be examined)
- (e) how existence of the S wave shadow zone as shown on seismic records has led geologists to a model of the Earth with a solid mantle and a liquid core

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.

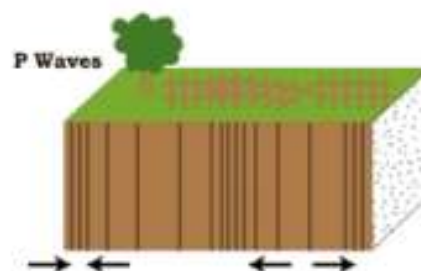


The 3 types of seismic waves.

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

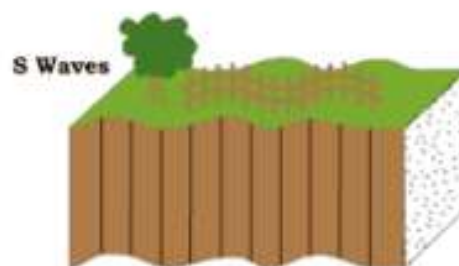
Primary (P) Waves. They are called primary waves because they arrive first. The main characteristics of primary waves are:

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



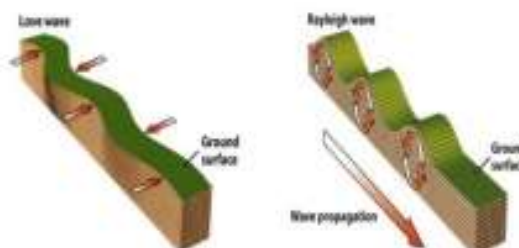
Secondary (S) Waves. They are called secondary waves because they arrive second. The main characteristics of secondary waves are:

- 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:

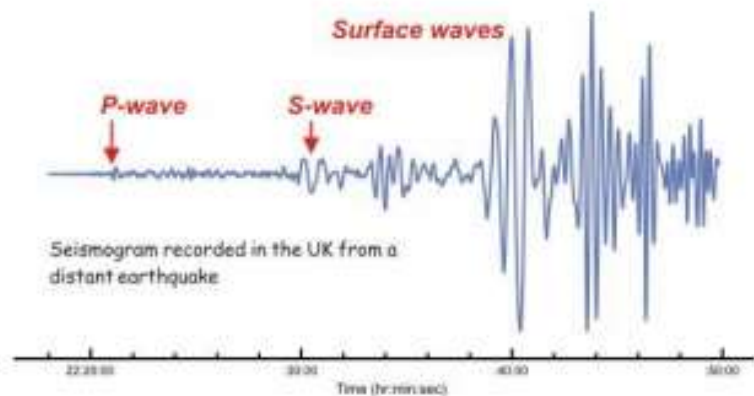
- Have higher amplitudes than P and S waves.
- These usually cause buildings to be knocked down.
- Formed from a combination of P and S waves.
- Generally slowest of the three waves.



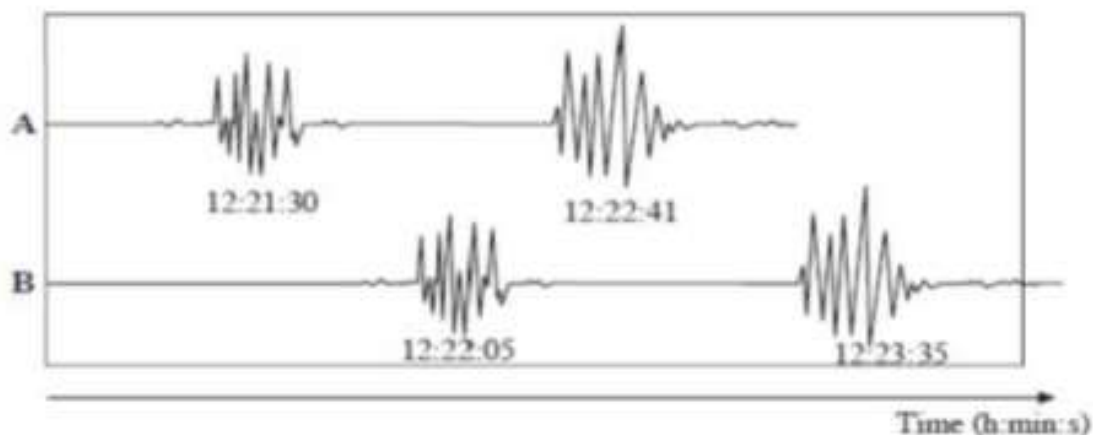
Seismogram.

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, $71 \div 12 = 5.92$ and then $5.92 \times 100 = 592\text{km}$

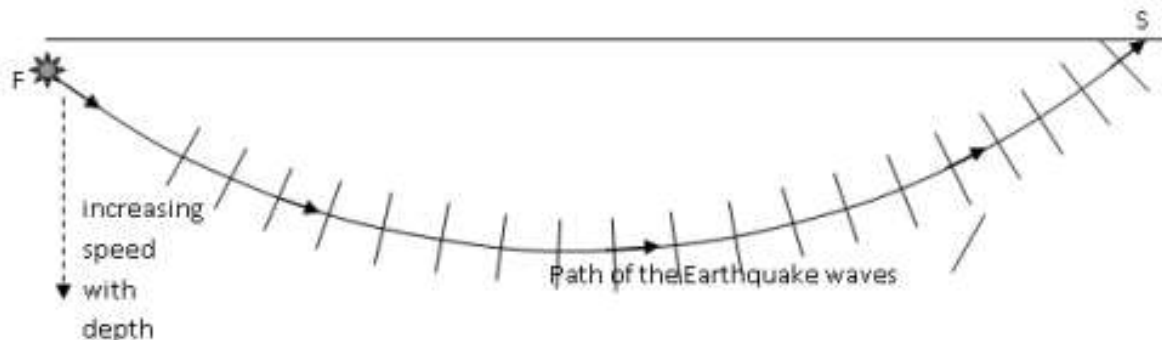
Refraction of seismic waves.

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

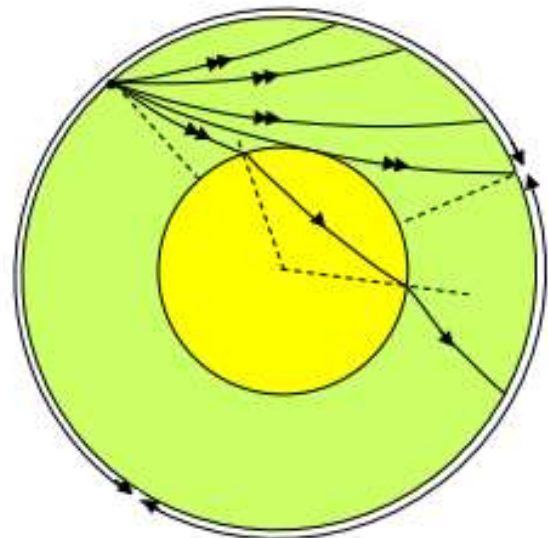
S = Seismometer



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.

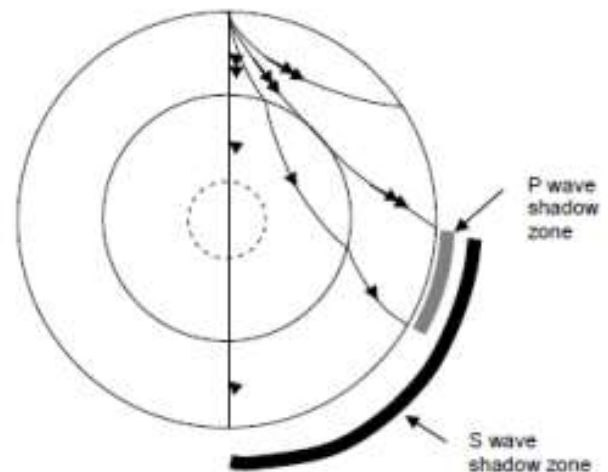
Shadow zones.

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.

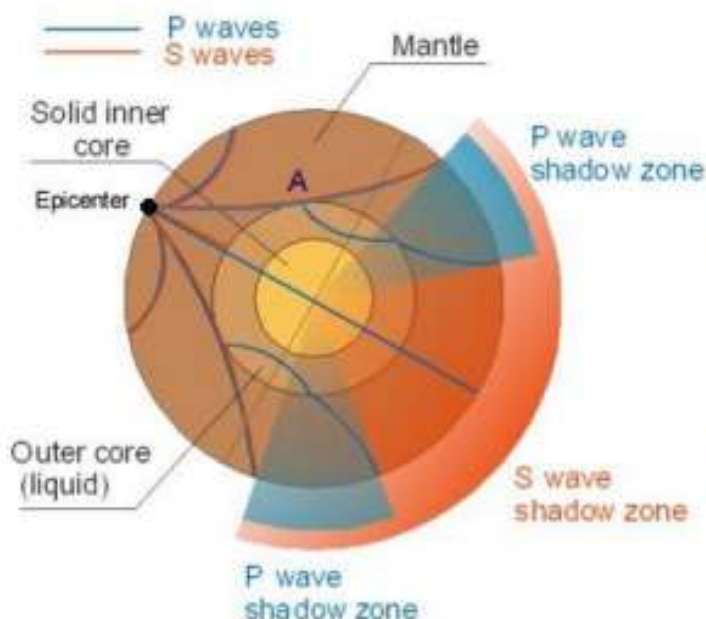
P and S waves travel **very differently** through the Earth. Initially P and S waves travel in all directions from the epicentre of an earthquake outwards. They are refracted as they travel from the epicentre and follow arcs.

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 $> 104^\circ$ 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 1.8 – Kinetic Theory

- (a) the concept of pressure qualitatively and select and use the relationship:

$$\text{pressure} = \frac{\text{force}}{\text{area}}; \quad p = \frac{F}{A}$$

- (b) the behaviour of a fixed quantity of gas under conditions of varying pressure, volume and temperature
- (c) how the behaviour of gases leads to the concepts of absolute zero and an absolute scale of temperature
- (d) temperatures in kelvin and **use the relationship:**

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

for gases including circumstances in which one of the three variables remains constant

- (e) the variation of the pressure of gases with volume and temperature qualitatively by applying a model of molecular motion and collisions
- (f) the equations:

$$Q = mc\Delta\theta \quad \text{and} \quad Q = mL$$

relating the heat transfer to changes of temperature and state respectively

- (g) **the explanation of changes in temperature and state of a substance, resulting from heat transfer, in terms of the behaviour of molecules**

SPECIFIED PRACTICAL WORK

- Determination of the specific heat capacity of a material

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.

REDUCING THE PRESSURE BY INCREASING THE AREA

• Skis have a large area to reduce the pressure on the snow so that they do not sink in too far.



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

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

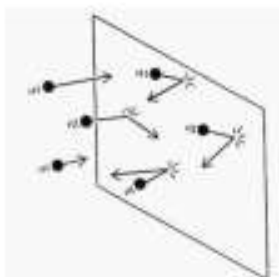
$$P = \frac{F}{A}$$

where force is measured in newtons, N
and so, area is measured in m² (or sometimes cm²)
 pressure is measured in N/m².

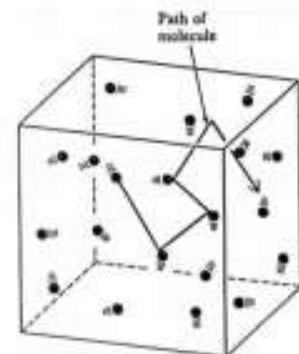
Another common unit for pressure is **Pascal, Pa**, but only if the area is measured in m² (rather than cm²).

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 no kinetic energy is 'lost' during collisions.



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.



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

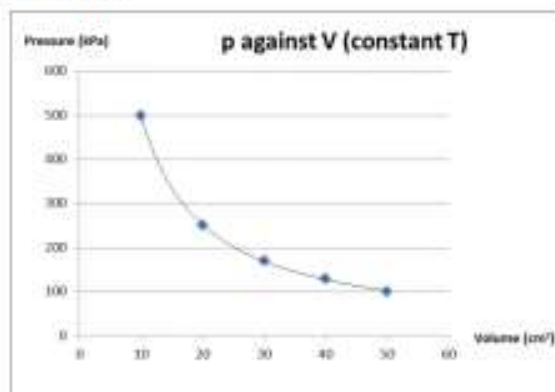
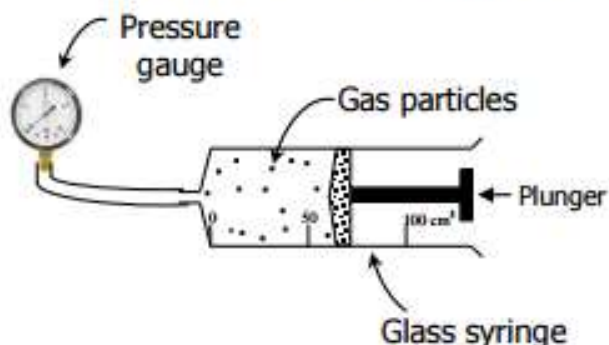
In gases, pressure is created by the gas particles colliding with the inside surface of the container. Every time a particle collides with the inside surface it creates an outward force on the container wall. Millions of such collisions on each square centimetre every second produces outward 'pressure'.

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.



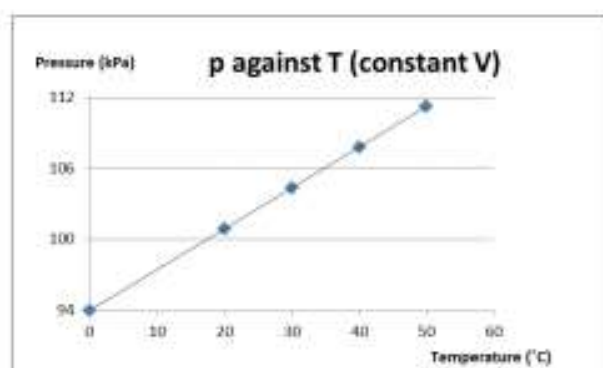
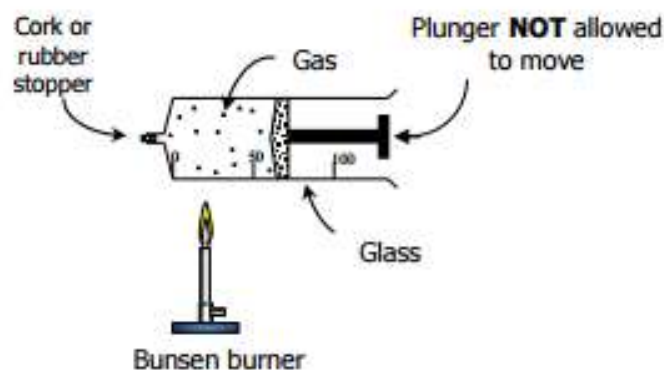
As the volume decreases, the pressure increases. In fact, you can see from the graph that if the volume halves, the pressure doubles. This means that pressure is inversely proportional to the volume, and hence we can write :

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

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 doubles when the temperature doubles. This means that pressure is directly proportional to the temperature, and hence we can write :

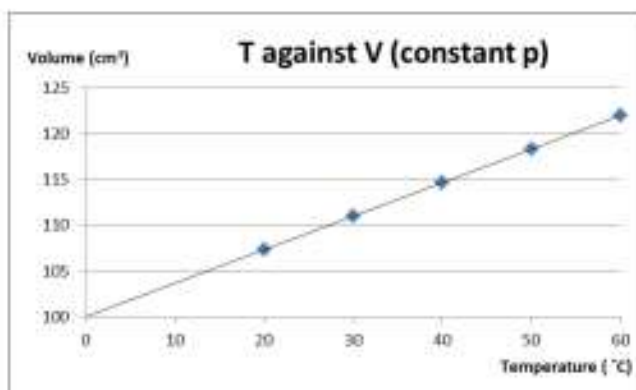
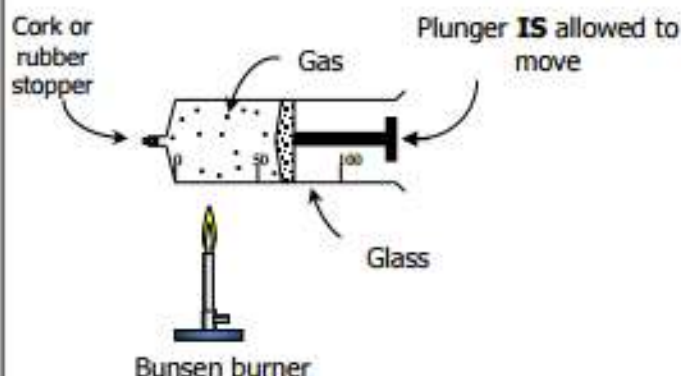
$$\frac{p}{T} = \text{constant}$$

Pressure, Volume & Temperature

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 :

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

or

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

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 :

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

$$\begin{aligned} 18\ ^\circ\text{C} &= 18 + 273 = 291\ \text{K} \\ 220\ ^\circ\text{C} &= 220 + 273 = 493\ \text{K} \end{aligned}$$

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

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

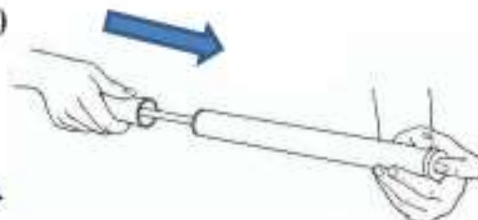
Note : This is likely to cause the can to explode, so do not try this at home !!! ;-)

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, imagine 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

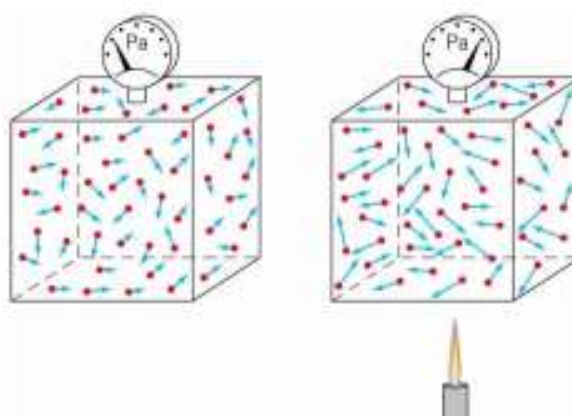
When the temperature of a gas is increased the pressure increases.

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

Specific heat capacity

Temperature and heat are not the same thing:

- ☛ temperature is a measure of how hot something is
- ☛ heat is a measure of the thermal energy contained in an object.

Temperature is measured in $^{\circ}\text{C}$, and heat is measured in J. When heat energy is transferred to an object, its temperature increase depends upon the:

- ☛ the mass of the object
- ☛ the substance the object is made from
- ☛ the amount energy transferred to the object.

For a particular object, the more heat energy transferred to it, the greater its temperature increase.

Specific heat capacity

The specific heat capacity of a substance is the amount of energy needed to change the temperature of 1 kg of the substance by 1°C . Different substances have different specific heat capacities. The table shows some examples.

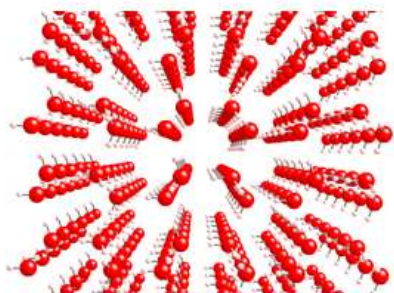
Heat capacities of different substances

Substance	Specific heat capacity in J / kg $^{\circ}\text{C}$
water	4181
oxygen	918
lead	128

Notice that water has a particularly high specific heat capacity. This makes water useful for storing heat energy, and for transporting it around the home using central heating pipes.

Phase changes

If phase changes occur, a different equation must be used. You probably will have to use the previous equation also (examples will be given). A phase change means a change in the state of matter (liquid, solid, gas). A phase change implies an input (or output) of heat. Let's use the example of water, which is a substance that we normally see in 3 different phases.



Crystal of ice showing water molecules aligned according to polarity

Solid water (ice) melts at 0 °C. If an ice cube is heated, it will begin to melt. The interesting thing is that its temperature is kept constant in this process: it will not rise a tenth of a degree! Even though heat is being supplied! That is because heat energy is being used to overcome the intermolecular forces which keep the water molecules together in a crystal lattice (image on the left). Different materials will take different amounts of energy to melt. This is called the **latent heat of fusion**. It is the energy required to transform a solid substance (already heated to its melting point) into a liquid.

Similarly, when water boils, it does so at a constant temperature. The heat in this case is also used to overcome intermolecular forces that are present (in liquid water they are weaker than in solid water). The energy required to transform a liquid substance (already heated to its boiling point) into a gas is called its **latent heat of vaporization**.

Substance	Melting Point(°C)	Latent Heat of Fusion - L_f (J/kg)	Boiling Point (°C)	Latent Heat of vaporization - L_v (J/kg)
Water	0	3.33×10^5	100	2.26×10^6
Alcohol	-114	1.04×10^5	78	8.54×10^5
Aluminum	660	3.97×10^5	2450	1.14×10^7
Silver	961	8.82×10^4	2193	2.33×10^6
Gold	1063	6.44×10^4	2660	1.58×10^6

Values for specific heat capacities or specific latent heat will be given.

Interpretation of a cooling / heating curve.

Appreciation that latent heat does not increase the temperature of matter – the energy supplied is used for the change of state to take place.

Define specific heat capacity as the amount of heat energy required to increase the temperature of 1 kg of a substance by 1 °C.

Define specific latent heat of fusion as the amount of heat energy needed to change a mass of 1 kg of the substance from a solid at its melting point into a liquid at the same temperature.

The specific latent heat of vaporisation is the amount of heat energy required to change 1 kg of a liquid at its boiling point into a vapour without a change in temperature.

Be able to relate the standard definitions to specific examples e.g. water has a specific heat capacity of 4 200 J / kg °C this means that 4 200 J of energy is required to increase the temperature of 1 kg of water by 1 °C.

**In terms of bond breaking or bond formation during changes of state.
A smaller number of bonds are broken during fusion than vaporisation so this means more energy is required for vaporisation to occur.**

Specified Practical work

Determination of the specific heat capacity of a material

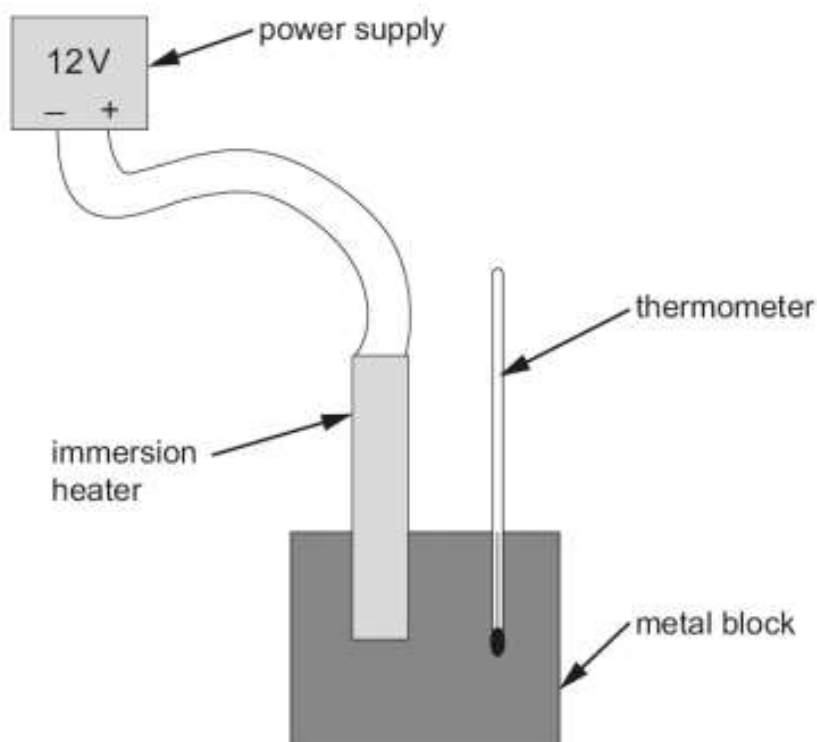
Introduction

You will determine the specific heat capacity of metals by measuring the heat energy transferred to the metal by an immersion heater and the temperature rise of the metal.

Apparatus

1 kg metal block
stopwatch
12V d.c. power supply
connecting leads
50W 12V immersion heater
thermometer

Diagram of Apparatus



Method

1. Ensure the power supply is switched off.
2. Place the immersion heater and thermometer in the holes provided in the metal block.
3. Record the initial temperature of the metal block.
4. Switch on the 12V power supply.
5. Record the temperature of the metal block every minute for 10 minutes.

Analysis

1. The heat energy transferred to the metal can be calculated from the equation:

$$\text{Energy} = \text{Power} \times \text{Time (seconds)}$$

2. The specific heat capacity (c) of the metal can be calculated from:

$$Q = mc\Delta\theta$$

Where:

Q = Heat energy supplied

m = Mass of block

$\Delta\theta$ = Temperature rise of block

Calculate the specific heat capacity of the metal.

Risk Assessment

Hazard	Risk	Control measure
Hot immersion heater can burn	Moving hot immersion heater	Do not switch on the immersion heater unless in the metal block. Allow to cool before touching

Unit 1.9 – Electromagnetism

- (a) the magnetic field patterns of bar magnets, straight wires and solenoids
- (b) how a magnet and a current carrying conductor exert a force on one another (the motor effect) and use Fleming's left hand rule to predict the direction of one of the following: force on the conductor, the current and the magnetic field when two are provided
- (c) **the equation that links the force (F) on a conductor to the strength of the field (B), the current (I) and the length of conductor (l), when the field and current are at right angles:**
 $F = BIl$
- (d) a simple d.c. motor, by predicting its direction of rotation and understand qualitatively the effect on increasing the current, magnetic field strength and number of turns
- (e) the conditions in which a current is induced in circuits by changes in magnetic fields and the movement of wires
- (f) electromagnetic induction to explain the operation of a simple a.c. electric generator including the factors upon which its output depends
- (g) the direction of the induced current in a generator to the direction of the magnetic field and the direction of rotation of the coil
- (h) the operation of a transformer qualitatively by reference to electromagnetic induction
- (i) how the output of a 100% efficient transformer depends upon the number of turns on the coils:
$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

SPECIFIED PRACTICAL WORK

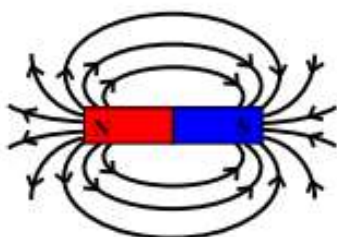
- Investigation of the output of an iron-cored transformer

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 :

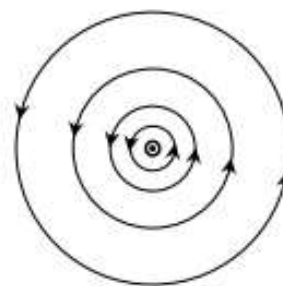
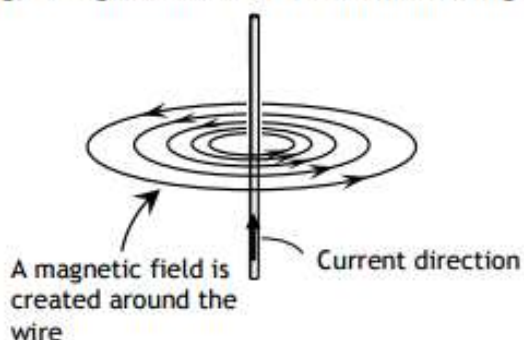
A bar magnet



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.

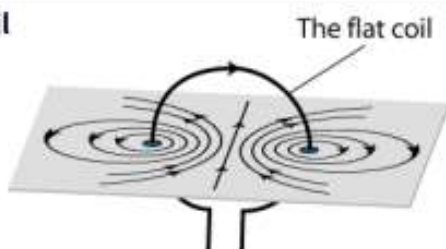
A long, straight wire with a current flowing through it



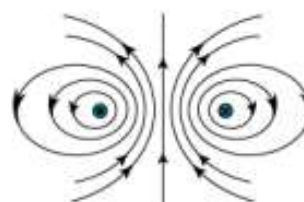
Plan view (bird's-eye)

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

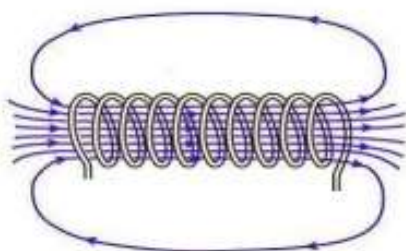


Magnetic field pattern generated by a flat coil



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.

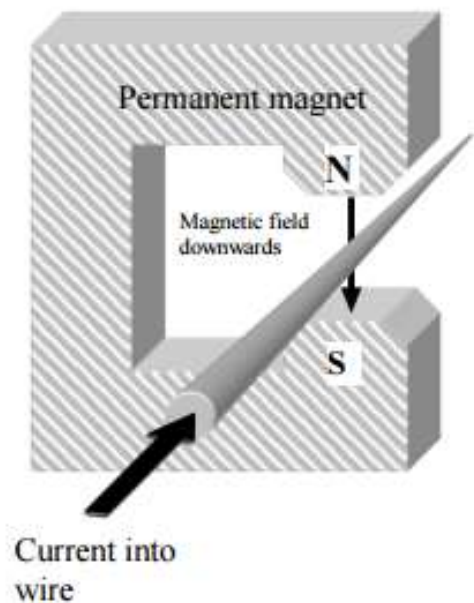
Also, notice that the shape is very similar to that of the magnetic field around a bar magnet.

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'.

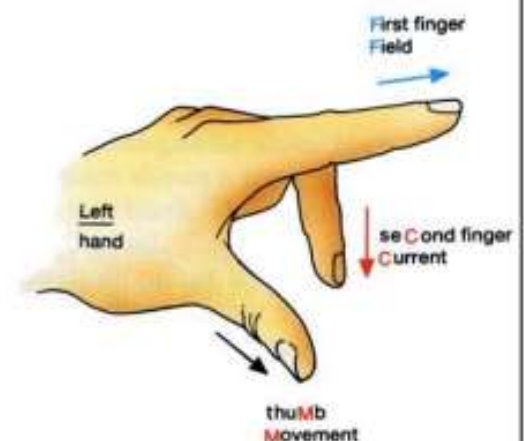
It's possible to predict the direction of the force by using **Fleming's LEFT hand rule**.

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

the **F**irst finger is in the direction of the **F**ield

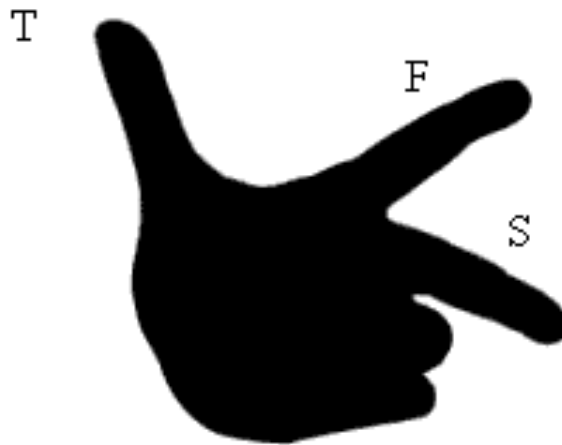
the **s**e**C**ond finger is in the direction of the **C**urrent

and the **th**u**M**b is in the direction of **M**otion.



Force on a current carrying wire

Fleming's left hand rule



First finger = Field
seCond finger = Current
thuMb = Movement

The force can be calculated using the following equation:

$$F = BIL$$

Where B = Magnetic flux density or magnetic field strength (T or $NA^{-1}m^{-1}$)

L = Length perpendicular to the field (m)

F = Force (N)

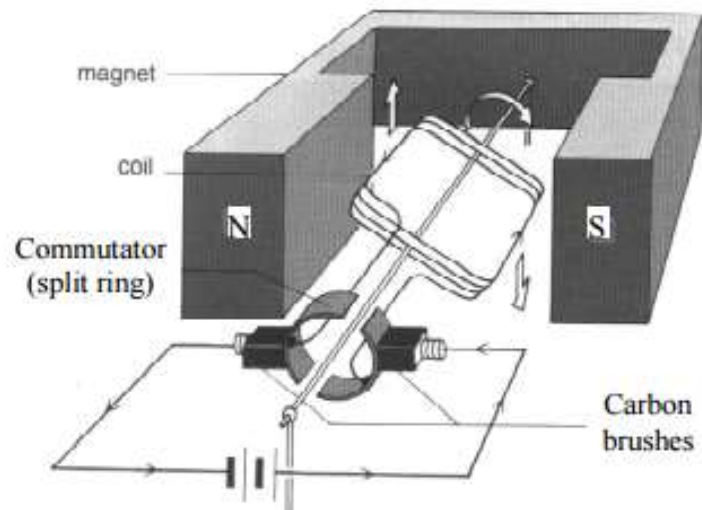
I = Current (A)

Note that the wire must be perpendicular to the field in order to experience a force.

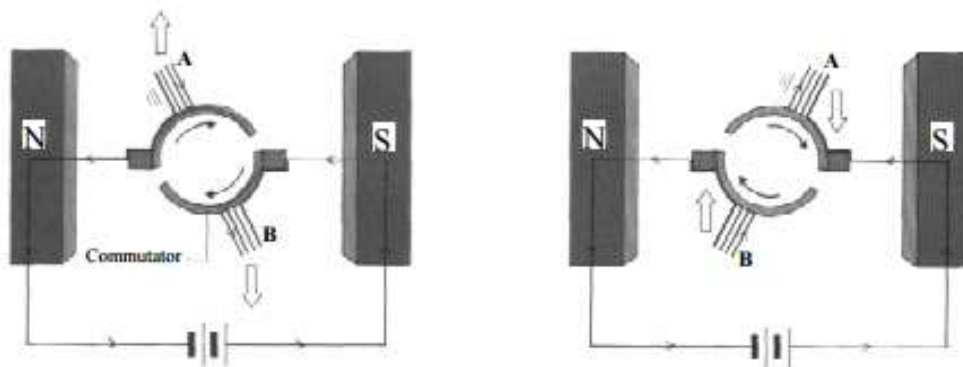
The Motor

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.

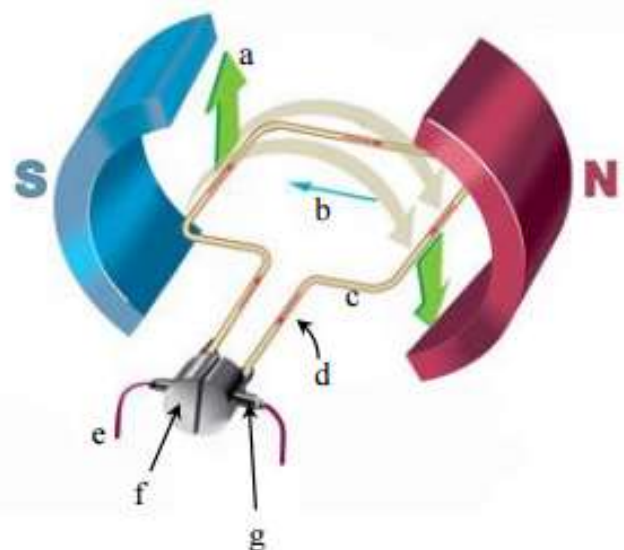


The split ring commutator ensures that the force on any wire on the left hand side of the motor is always directed upwards, and that the force on the right hand side is always downwards. This makes sure that the coil turns continuously in one direction.



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



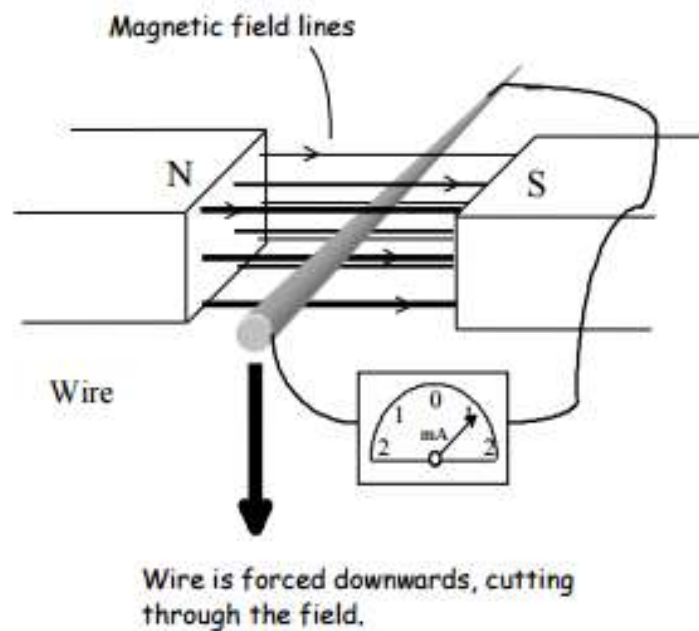
Answer : 1=f, 2=e, 3=b, 4=a, 5=c, 6=d, 7=g

Electromagnetic Induction

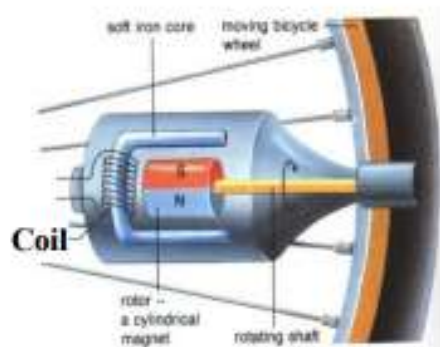
If a metal wire is forced to move through a magnetic field (or a magnetic field is moved through a wire), a **voltage** is produced across the wire.

If this wire is part of a complete circuit, this voltage will push a current around the circuit.

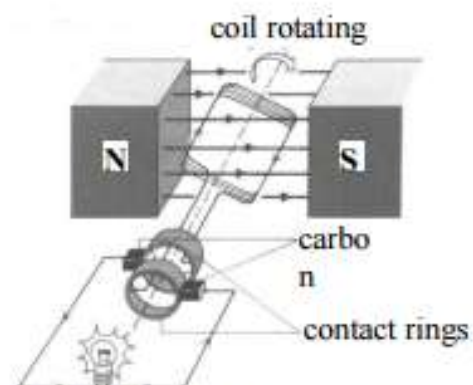
Another way of saying this would be :
 “electricity is induced (created) when a wire CUTS through magnetic field lines”.



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

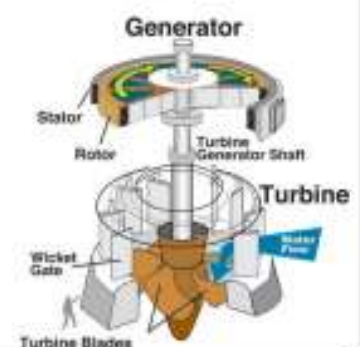


A small generator, e.g. a wind up torch

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.

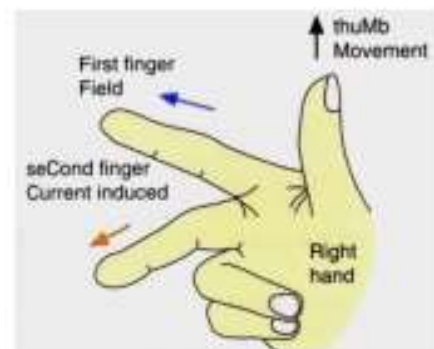
The direction of the induced current can be predicted by using Fleming's **RIGHT** hand rule.

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

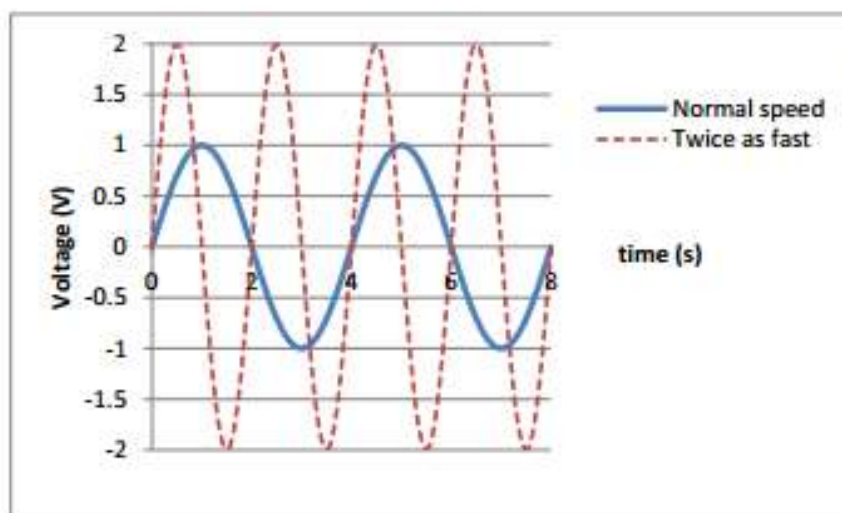
and the second finger is in the direction of the Current



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 :



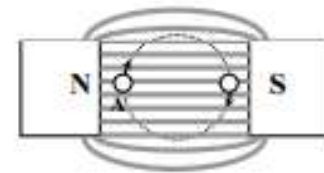
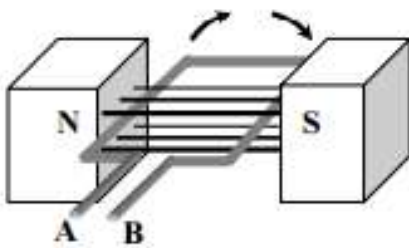
Notice the effect of **doubling** the speed of rotation of the generator.

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

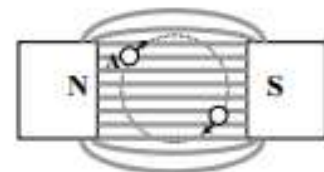
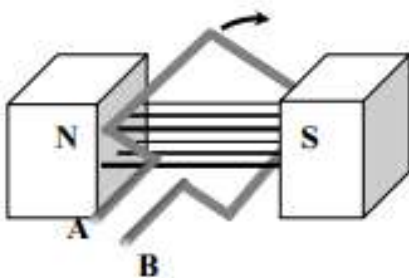
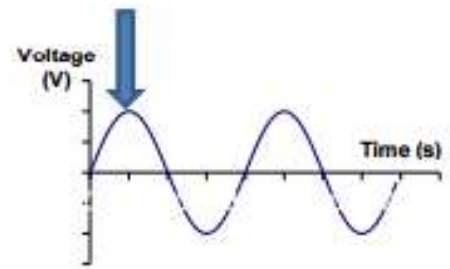
Also, the peak voltage is now **twice** as large since the coil in the generator is breaking through magnetic field **twice** as quickly - see point 1 at the top of the page !

Generators

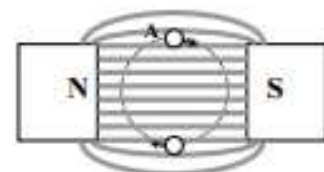
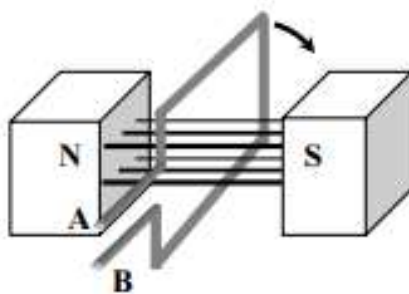
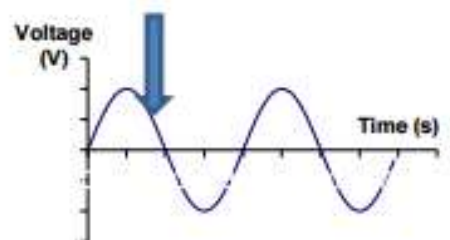
Understanding the shape of the output voltage of a generator



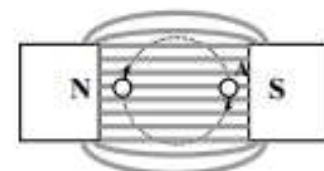
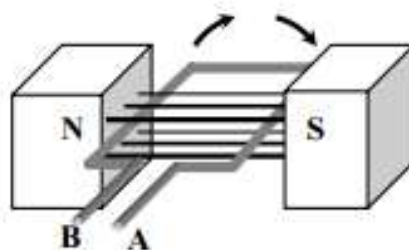
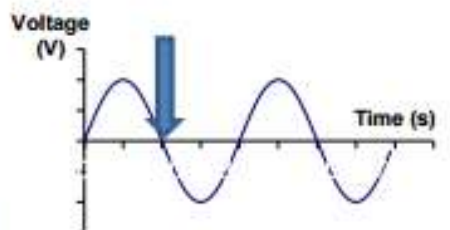
The coil is cutting through magnetic field lines at its greatest rate, and so this is when the maximum voltage/current is produced.



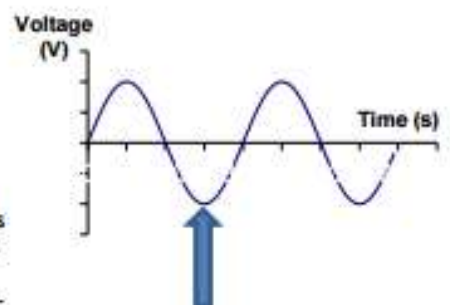
Side "A" of the coil is still cutting upwards through magnetic field lines, and so the voltage is still positive. However, because of the angle, the coil isn't cutting the lines as quickly as before, and so there's less voltage.



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



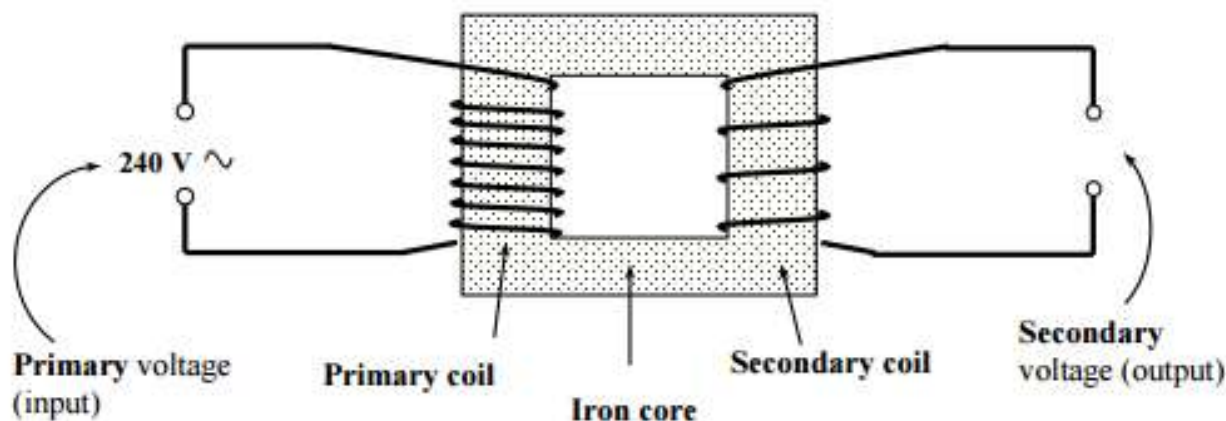
Once again lines are being cut at maximum rate, but side "A" of the coil is now cutting down through the magnetic field. This changes the direction of the voltage.



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 $N_1 = 2000$.

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

Investigation of the output of an iron-cored transformer

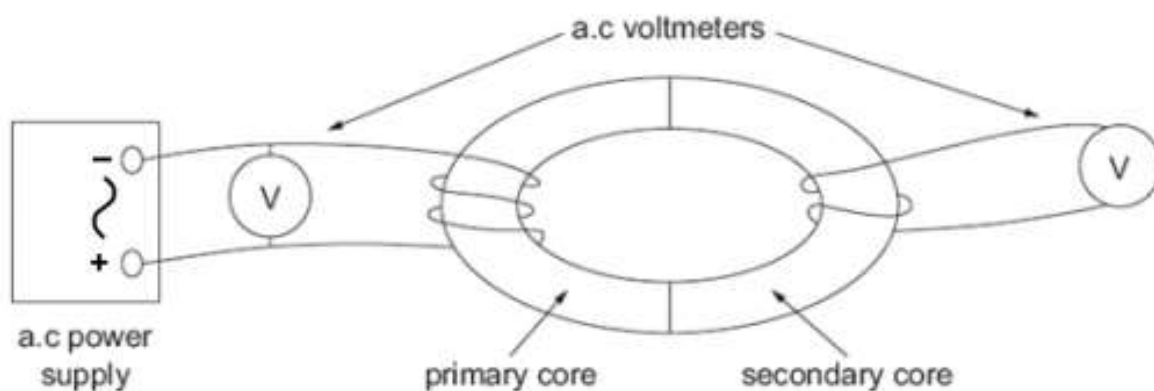
Introduction

A transformer can be constructed from iron 'C' cores and flexible insulated wire. You will investigate the relationship between the number of turns on the secondary coil and secondary voltage.

Apparatus

C-cores (20/40/60/80/100 turns)
a.c. power supply
2 × a.c. voltmeters $\pm 0.01\text{V}$
connecting wires
crocodile clips

Diagram of Apparatus



Method

1. Ensure the power supply is switched off.
2. Set up the circuit as shown with 100 turns on the primary core and 20 turns on the secondary core.
3. Switch on the power supply.
4. Record the voltages.
5. Turn off the power supply.
6. Add 20 further turns to the secondary core.
7. Repeat steps 3 to 6 to until there are 100 turns on the secondary core.

Analysis

1. Draw a graph of the number of turns on the secondary core (N_2) against the secondary voltage (V_2).

Risk Assessment

Hazard	Risk	Control measure
Hot wires can burn	Burning skin on hot wire	Do not exceed 4 V Switch off the power supply after taking readings Allow wire to cool before handling